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Observational learning of motor skills: Looking for optimal models

par

Hassan Rohbanfard

Département de kinésiologie

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Présentée par :

Hassan Rohbanfard

a été évaluée par un jury composé des personnes suivantes :

Julie Messier, président-rapporteur

Luc Proteau, directeur de recherche

Claude Dugas, membre du jury

Timothy D. Lee, examinateur externe

Roseline, Garon, représentant du doyen de la FESP

Résumé

L'observation d'un modèle pratiquant une habileté motrice promeut l'apprentissage de l'habileté en question. Toutefois, peu de chercheurs se sont attardés à étudier les caractéristiques d'un bon modèle et à mettre en évidence les conditions d'observation pouvant optimiser l'apprentissage. Dans les trois études composant cette thèse, nous avons examiné les effets du niveau d'habileté du modèle, de la latéralité du modèle, du point de vue auquel l'observateur est placé, et du mode de présentation de l'information sur l'apprentissage d'une tâche de timing séquentielle composée de quatre segments. Dans la première expérience de la première étude, les participants observaient soit un novice, soit un expert, soit un novice et un expert. Les résultats des tests de rétention et de transfert ont révélé que l'observation d'un novice était moins bénéfique pour l'apprentissage que le fait d'observer un expert ou une combinaison des deux (condition mixte). Par ailleurs, il semblerait que l'observation combinée de modèles novice et expert induise un mouvement plus stable et une meilleure généralisation du timing relatif imposé comparativement aux deux autres conditions. Dans la seconde expérience, nous voulions déterminer si un certain type de performance chez un novice (très variable, avec ou sans amélioration de la performance) dans l'observation d'une condition mixte amenait un meilleur apprentissage de la tâche. Aucune différence significative n'a été observée entre les différents types de modèle novices employés dans l'observation de la condition mixte. Ces résultats suggèrent qu'une observation mixte fournit une représentation précise de ce qu'il faut faire (modèle expert) et que l'apprentissage est d'autant plus amélioré lorsque l'apprenant peut contraster cela avec la performance de modèles ayant moins de succès.

Dans notre seconde étude, des participants droitiers devaient observer un modèle à la première ou à la troisième personne. L'observation d'un modèle utilisant la même main préférentielle que soi induit un meilleur apprentissage de la tâche que l'observation d'un modèle dont la dominance latérale est opposée à la sienne, et ce, quel que soit l'angle d'observation. Ce résultat suggère que le réseau d'observation de l'action (AON) est plus sensible à la latéralité du modèle qu'à l'angle de vue de l'observateur. Ainsi, le réseau d'observation de l'action semble lié à des régions sensorimotrices du cerveau qui simulent la programmation motrice comme si le mouvement observé était réalisé par sa propre main dominante.

Pour finir, dans la troisième étude, nous nous sommes intéressés à déterminer si le mode de présentation (en direct ou en vidéo) influait sur l'apprentissage par observation et si cet effet est modulé par le point de vue de l'observateur (première ou troisième personne). Pour cela, les participants observaient soit un modèle en direct soit une présentation vidéo du modèle et ceci avec une vue soit à la première soit à la troisième personne. Nos résultats ont révélé que l'observation ne diffère pas significativement selon le type de présentation utilisée ou le point de vue auquel l'observateur est placé. Ces résultats sont contraires aux prédictions découlant des études d'imagerie cérébrale ayant montré une activation plus importante du cortex sensorimoteur lors d'une observation en direct comparée à une observation vidéo et de la première personne comparée à la troisième personne.

Dans l'ensemble, nos résultats indiquent que le niveau d'habileté du modèle et sa latéralité sont des déterminants importants de l'apprentissage par observation alors que le point de vue de l'observateur et le moyen de présentation n'ont pas d'effets significatifs sur l'apprentissage d'une tâche motrice. De plus, nos résultats suggèrent que la plus grande activation du réseau d'observation de l'action révélée par les études en imagerie mentale durant l'observation d'une action n'induit pas nécessairement un meilleur apprentissage de la tâche.

Mots-clés : Apprentissage par observation, apprentissage moteur, tâche de timing, habileté motrice, timing relatif, réseau d'observation de l'action, latéralité du modèle, observation en direct, observation vidéo, observation allocentrée, observation égocentrée, point de vue d'observation, observation à la première personne, observation à la troisième personne.

Abstract

Observation of a model practicing a motor skill has been shown to promote the learning of that skill. However, relatively little is known regarding the attributes of a good model and the conditions of observation that can optimize learning. In the three studies reported in this thesis, we investigated the effects of the model's skill level, the model's handedness, the observation perspective, and the medium of presentation on the learning of a sequential, four-segmented timing task. In the first experiment of the first study, we had participants observe a novice, an expert, or a combination of both novice and expert models (i.e., mixed model). The results of the retention/transfer tests revealed that observation of the novice model was not as effective for the learning of the task as observation of the expert and mixed models. Importantly, a mixed schedule of novice and expert observation resulted in more stable movement time and better generalization of the imposed relative timing pattern than observation of either a novice or an expert model. In the second experiment, we wanted to determine whether a certain type of novice performance (highly variable, with or without performance improvement) in a mixed observation schedule results in better learning of the task. No significant differences were revealed with respect to the type of novice model used in a mixed schedule of observation. These results suggest that mixed observation provides an accurate template of what to do (expert observation), which is enhanced when it can be contrasted with the performance of less successful models.

In our second study, right-handed participants were asked to observe, from a first-person or a third-person perspective, a right-handed (i.e., same-handed) or left-handed (i.e., opposite-handed) model performing the experimental task. Observation of the same-handed model resulted in better learning of the task than did observation of the opposite-handed model, regardless of the observation perspective. This suggests that the action observation network (AON) is more sensitive to the model's handedness than to the observer's viewpoint. Thus, the AON seems to be linked to sensorimotor regions of the brain that simulate motor programming as though the observed movement was performed with one's own dominant hand.

Finally, in the third study, we were interested to determine whether the medium of presentation (live vs. video) affects observational learning and whether this effect would be mediated by the observer's viewpoint (1st vs. 3rd person). In that regard, participants observed a live model or a video presentation of the model from a first- or third-person perspective. Our results revealed that observation did not differ significantly as a function of the media or the perspective of observation. These results are inconsistent with the predictions of brain imaging studies that show a larger activation of the sensorimotor cortex during live observation compared with video observation and from a first-person compared with the third-person perspective.

Taken together, our results indicate that the model's skill level and handedness are important determinants of observational learning, whereas the observer's viewpoint and the medium of observation had no significant impact on motor task learning. In addition, our

results suggest that the larger activation of AON revealed in brain imaging studies *during* action observation does not necessarily result in or indicate better *learning* of the task.

Keywords : Observational learning, motor learning, timing task, motor skill**,** relative timing, action observation network, model handedness, live observation, video observation, allocentric observation, egocentric observation, observation perspective, first-person perspective, third-person perspective

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Abbreviations

|CE|: Absolute constant error

ACQ: Acquisition

AON: Action observation network

BCA: Broca area

BOLD: Blood oxygenation level-dependent

CCWFF: Counterclockwise force field

CI: Contextual interference

CNS: Central nervous system

CWFF: Clockwise force field

EEG: Electroencephalography

fMRI: Functional magnetic resonance imaging

GMP: Generalized motor program

IT: Intermediate time

KR: Knowledge of results

LH: Left-handed

LSD: Least significant difference

MEG: Magnetoencephalographic

MEPs: Motor-evoked potentials

PET: Positron emission tomography

PRT: Pre-test

RET: Retention

RH: Right-handed

RMSE: Root mean square error

SD: Standard deviation

TMS: Transcranial magnetic stimulation

TMT: Total movement time

TR: Transfer

VE: Variable error

To the memory of my parents!

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Introduction

Motor skills are an essential component of many activities in our daily life. Psychologists define motor skills as “procedural knowledge.” This includes learning to ride a bike, play a musical instrument, or the skills of a sport or activity such as swimming, tennis, or martial arts. In general, a motor skill can be described as “a learned sequence of movements that combine to produce a smooth, efficient action in order to master a particular task” (Magill, 1993). Many factors contribute to the development of motor skills; some of them are uncontrollable, such as genetic factors, whereas other factors, such as practice, are controllable. How motor skills are practiced and taught has been a subject of considerable research over the last century. There is no doubt that one of the most efficient determinants of motor skill acquisition is overt/physical practice, as advocated by early theories of motor learning (Adams, 1971; Fitts, 1964; Schmidt, 1975; Vince, 1949). Specifically, physical practice results in a series of neurophysiological changes in the central nervous system (CNS), leading to the acquisition of the practiced motor skill (Jensen, Marstrand, & Nielsen, 2005; Pascual-Leone et al., 1995; Sanes, 2003).

Nonetheless, physically practicing a task is not always possible or may not be the best way to promote learning of the task (Schmidt & Lee, 2005). This could be the case, for example, when there is a high risk of injury in performing a motor task or when a task has to be relearned following an injury in physiotherapy and rehabilitation sessions. In such instances, one of the most frequently used and proposed methods for motor skill learning is observational practice, in which participants observe a model displaying the skill to be learned. In addition, observation can be a more cost- and time-efficient strategy than physical practice in a number of practical settings, such as the teaching of sport-related motor skills, physical therapy exercises, and surgical procedures.

Despite the considerable amount of research that has been done in the context of observational learning, relatively little is known about the attributes of a good/optimal model. For example, would it be better to observe a novice model, an expert model, or a combination of the two models (hereafter called a mixed model)? Would it be better to observe a model performing a task with the same hand as the observer's dominant hand (hereafter called a same-handed model) or with the opposite hand (hereafter called an opposite-handed model)? Concerning the perspective of observation, would it be better to position the observer in the same perspective as the model (i.e., 1st-person perspective; also called egocentric) or to position the observer face to face with the model (i.e., 3rd-person perspective; also called allocentric)? Finally, would it be better to observe a live or a video presentation of the model? The specific goals of the studies reported in this thesis were to address the above questions.

This thesis is composed of five chapters. In chapter 1, I review the behavioral and brain imaging literature on observational learning. Chapters 2–4 present three experimental studies according to the format required by the journals to which they have been submitted. Finally, chapter 5 provides a summary and a general discussion of the major findings of the studies.

Chapter 1: Review of the literature

Learning through observation

Observation has been shown to be beneficial for learning or to reduce the amount of overt physical practice required to reach proficiency (Blandin, Lhuisset, & Proteau, 1999; Carroll & Bandura, 1990; Ferrari, 1996; Schmidt, 1988; Scully & Newell, 1985). For instance, previous studies have shown that observation promotes learning of many different tasks such as sequential timing (Blandin et al., 1999; Blandin, Proteau, & Alain, 1994), coincidence anticipation (Blandin & Proteau, 2000, Experiment 2; Weeks, 1992), serial reaction time (Heyes & Foster, 2002; Kelly, Burton, Riedel, & Lynch, 2003; Osman, Bird, & Heyes, 2005; Vinter & Perruchet, 2002), action pattern production (Carroll & Bandura, 1982; Weeks & Anderson, 2000), and gross as well as fine motor skills (Landers, 1975; Martens, Burwitz, & Zuckerman, 1976; Pollock & Lee, 1992; Southard & Higgins, 1987; see Hodges, Williams, Hayes, & Breslin, 2007; McCullagh & Weiss, 2001; Vogt & Thomaschke, 2007; Wulf & Mornell, 2008 for reviews on observational learning).

Mechanisms affected by observation

How observational learning takes place and what information is learned from observation are questions that have stimulated considerable research. A popular theoretical account of observational learning suggests that observation promotes the formation of a cognitive representation of the task to be learned (Bandura, 1977, 1986; "perceptual blueprint" in Sheffield's [1961] terminology). This representation can serve as a standard of reference against which the observer's own performance is compared (Bandura, 1986). According to Bandura, there are four constituent sub-processes for observation to promote learning. The observer should attend to the relevant information throughout observation (attention sub-process), retain the key information for imitation (retention sub-process), be able to use the retained information to reproduce the observed task (production sub-process), and have the desire for reproduction of the task (motivation sub-process).

In addition to the formation of a perceptual blueprint of what to perform, observation also results in the observer developing error detection and correction mechanisms (Adams, 1986; Badets, Blandin, Wright, & Shea, 2006; Black & Wright, 2000; Black, Wright, Magnuson, & Brueckner, 2005; Blandin & Proteau, 2000; Carroll & Bandura, 1990). In that regard, Blandin and Proteau (2000) showed that following observation of a model practicing a task participants were able to efficiently estimate their own errors and to use this estimation to correct/improve their own performance (Experiment 1). Moreover, in a second experiment, Blandin and Proteau (2000) also showed that observation of a model receiving biased knowledge of results (KR), leading to a predictable biased performance that produced a similar bias in the observer's own performance. This suggests that KR during physical practice and observation results in the development of a very similar standard of reference as well as mechanisms for the detection and correction of errors.

Concerning “what” is perceived during observation, previous research has provided empirical evidence that all invariant features of a generalized motor program (GMP; Schmidt, 1975), including the sequence of movements, the relative timing, and the relative force required for reproduction of a motor skill, can be learned through observation (Badets, Blandin, & Shea, 2006; Blandin et al., 1999; Mattar & Gribble, 2005; Porro, Facchin, Fusi, Dri, & Fadiga, 2007; Scully & Newell, 1985). In addition, observation improves the movement parameterization of a particular GMP (Blandin et al., 1999; Scully & Newell, 1985).

Using a different theoretical perspective, Scully and Newell (1985) proposed that the crucial information available during observation consists of the topological characteristics of the relative motion of the task. They proposed that this relative motion pattern is probably what the observer learns initially. Then, with repeated exposure to the task, the observer might learn how to parameterize this movement pattern. This proposal was based on studies showing that observers who are allowed to see the displacement over time of light spots located on the main joints of a human participant were able to identify immediately whether this participant was walking, running, cycling, limping, or dancing (Johansson, 1973), whether the participant was male or female (Barclay, Cutting, & Kozlowski, 1978; Mather & Murdoch, 1994), and whether he or she was a friend or a stranger (Cutting & Kozlowski, 1977). Thus, it appears that all activities have a unique relative motion pattern that is recognizable by non-naïve observers.

In the same vein, Blandin, Lhuisset, and Proteau (1999) investigated the effects of observation on the learning of a sequential four-segmented timing task. Specifically, participants were asked to complete in succession the first, second, third and fourth segments of the experimental task in a movement time of 900 milliseconds (ms). In addition, each of the four segments had to be completed in 25% of the total movement time (i.e., 225 ms for each segment). This required the participants to learn a constrained relative timing that was different from the naturally emerging relative timing of the task. Their results showed that the participants learned the movement sequence and the constrained relative timing as well as the total movement time of the task. They also showed that the participants were able to rescale the relative timing pattern that they had observed to a different movement time. This was supported by the results of a transfer test in which participants completed the task in a movement time of 1200 ms while keeping the same relative timing for each segment (e.g., 300 ms). These results suggest that observation enabled participants to learn a new GMP and its parameterization. However, it was not clear from this study whether the relative force could also be learned through observation.

More recently, Mattar and Gribble (2005) studied the effects of observation on the learning of reaching movements performed in different force fields, in which the model's arm was deviated in different directions by a robotic device. Three groups of participants were required to observe a video showing a model learning to counteract a clockwise force field (CWFF), a counterclockwise force field (CCWFF), or nothing (i.e., a control group). All participants were then tested in a CWFF. Their results showed that the CWFF group performed better than a control group that had not received any observation, whereas the CCWFF group performed more poorly. This suggests that observation enables an individual to apply the force information for programming the observed task (for similar results, see Porro et al., 2007).

The results reviewed so far suggest that observation enables the observer to determine the key spatial and/or temporal features of the task, which removes the need to create a cognitive representation of the action pattern through trial and error (Bandura, 1986; Blandin et al., 1994; Buchanan & Dean, 2010; Carroll & Bandura, 1982; Pollock & Lee, 1992; Schmidt & Lee, 2005; Scully & Newell, 1985). In fact, it has been proposed that observation-based learning and physical practice-based learning might engage one in similar information processing mechanisms (Adams, 1986; Bandura, 1977, 1986; Blandin & Proteau, 2000; Blandin et al., 1994; Kohl & Shea, 1992; Lee & White, 1990; Shea, Wright, Wulf, & Whitacre, 2000).

Observation and the Action Observation Network

The above proposition is supported by recent neurophysiological and brain-imaging studies illustrating that “mirror neurons” in different parts of the brain including premotor cortex, inferior parietal lobule, superior temporal sulcus, supplementary motor area, cingulated gyrus, and the cerebellum, which form an action observation network (AON), are activated both when individuals perform a given motor task and when they observe others perform that same motor task (Buccino et al., 2001; Cisek & Kalaska, 2004; Cohen

& Andersen, 2002; Cross, Kraemer, Hamilton, Kelley, & Grafton, 2009; Dushanova & Donoghue, 2010; Gallese, Fadiga, Fogassi, & Rizzolatti, 1996; Jeannerod, 2001; Kalaska, Scott, Cisek, & Sergio, 1997; Rizzolatti, Fadiga, Gallese, & Fogassi, 1996; see Cattaneo & Rizzolatti, 2009; Rizzolatti & Craighero, 2004; Rizzolatti, Fogassi, & Gallese, 2001 for recent reviews). Thus, the AON appears to link observation and execution of motor skills in order for us to understand the behavior of others (Carey, 1996; Fogassi, 2011; Gallese et al., 1996; Rizzolatti et al., 2001).

Direct evidence for the existence of mirror neurons comes from studies on non-human primates (DiPellegrino, Fadiga, Fogassi, Gallese, & Rizzolatti, 1992; Gallese et al., 1996; Rizzolatti et al., 1996); there is no research directly recording the activity of single neurons from the AON in humans. Nonetheless, a large number of studies strongly, although indirectly, suggest that an action-observation matching system (i.e., mirror neurons) similar to that discovered in monkeys also exists in humans (e.g., Fadiga, Fogassi, Pavesi, & Rizzolatti, 1995; Gallese & Goldman, 1998; Rizzolatti & Craighero, 2004). For example, Fadiga and colleagues (1995) required participants to observe a model grasping objects (transitive actions) or performing meaningless arm movements in the air (intransitive movements). Observation of objects and detection of the dimming of a small spot of light were used as control conditions. The authors recorded motor-evoked potentials (MEPs) of the various hand and arm muscles elicited by transcranial magnetic stimulation (TMS) of the observer's left motor cortex. The results revealed increased MEPs during observation of both transitive and intransitive movements in comparison with the control conditions. Interestingly, increased MEPs were found only in those muscles that the observers used when overtly performing the observed movements. This suggests that observation of actions activates the premotor cortex in humans, as happens in non-human primates.

Observers need physical practice

Despite the fact that both observational practice and physical practice engage one in similar information processing mechanisms, some brain-imaging studies have shown that the AON is more activated during action execution than during action observation (DiPellegrino et al., 1992; Iacoboni & Dapretto, 2006; Woodruff & Maaske, 2010; but see also Cochin, Barthelemy, Roux, & Martineau, 1999; Lepage, Saint-Amour, & Théoret, 2008; Muthukumaraswamy & Johnson, 2004). Recently, Woodruff and Maaske (2010) asked participants to observe videos of a model's right hand at rest (rest observation), the same hand tapping the forefinger and thumb together (action observation) or executing the same right-hand movement as that observed (action execution). Electroencephalography (EEG) recordings showed a significantly greater "μ suppression"[1] and thus a greater activation in the left hemisphere for action execution than for action observation.

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[1] EEG oscillations in the μ frequency (8-13 Hz) over sensorimotor cortex are thought to reflect mirror neuron activity. It has been shown that μ power is reduced (mu suppression) both when individuals perform actions and when they observe others performing actions. The greater μ suppression indicates more activation of the mirror neuron system.

At the behavioral level, it has also been shown that, in some instances, observation per se is not as effective as physical practice for learning a motor task (e.g., Bandura, 1969; Blandin et al., 1994; Carroll & Bandura, 1982; Deakin & Proteau, 2000; Scully & Newell, 1985; Shea et al., 2000; Trempe, Sabourin, Rohbanfard, & Proteau, 2011; see McCullagh, Weiss, & Ross, 1989 for a review). In these studies, a few physical practice trials with KR were needed for the effects of observation to become manifest. The physical practice trials seem to allow the observers to refine the cognitive representation developed through observation (Bandura, 1986), presumably because response-produced sensory feedback engages the learner in processes not used during observation (Scully & Newell, 1985; Shea et al., 2000; Weeks & Anderson, 2000; see also Mackay, 1981).

Weeks and Anderson (2000) illustrated that the interaction between observational practice and physical practice would be most effective for motor skill learning when participants experience observational practice early in the acquisition phase and then engage in physical practice trials at the end. Specifically, they investigated the effects of three different mixed schedules of observation and physical practice on learning an overhand volleyball serve. One group received all 10 demonstrations from an expert model prior to performing 30 physical practice trials (all-pre-practice group). Another group received one model demonstration followed by three physical practice trials, with this pattern of interspersing continued throughout the acquisition phase (interspersed group). A third group observed five demonstrations before any physical practice and then received one demonstration trial following every three physical practice trials so that observation was completed at mid-acquisition; the participants then physically practiced the task for 15 trials (combination group). Thus, all participants received 10 observational practice and 30 physical practice trials during acquisition. The results revealed higher form scores for the combination and all-pre-practice groups compared with the interspersed group. This suggests that a few uninterrupted physical practice trials scheduled once observation is terminated would allow for some trial-and-error learning occurring without the model as a reference.

In addition to the timing of observation in relation to the physical practice, it has been suggested that a variety of variables could potentially have an important role in observational learning of motor skills. In the following section, we review some of these influential factors including KR, schedule and amount of practice, and intention.

Factors influencing observational learning

In the context of observational learning, KR refers to the feedback that is provided to the model following a physical practice trial and that is also shared with the observer. In that regard, using a sequential timing task, Adams (1986) revealed that providing observers with a model’s KR results in better learning of the task than when such a feedback is not provided to the observers (see also McCullagh & Caird, 1990). De Jeager and Proteau (2003) indicated that verbal KR is a more effective source of information than auditory KR to promote learning of a new constrained relative timing pattern. More recently, Badets and Blandin (2004, 2005, 2010) investigated the effects of different KR schedules on learning through observation. As for physical practice, they reported beneficial effects of bandwidth KR (i.e., receiving KR only when the model's performance fell outside a pre-determined bandwidth, for example ±10% of target time) and low KR frequency (i.e., KR is provided following only 33% of the trials in comparison to receiving KR following all trials) for the observational learning of the absolute (Badets & Blandin, 2004, 2005; see also Badets, Blandin, Wright, & Shea, 2006) as well as the relative timing of a motor task (Badets & Blandin, 2010).

Another factor impacting observational learning is the extent of contextual interference (CI) experienced during observational practice. In a physical practice context, there is considerable evidence suggesting that a random practice schedule (i.e., high CI) results in better retention and transfer performance compared with a blocked practice schedule (i.e., low CI), probably because participants in a random practice condition are involved in more extensive cognitive processing activity (for reviews, see Lee & Magill, 1985; Magill & Hall, 1990). To test the effects of different practice schedules on observational learning, Blandin, Proteau, and Alain (1994) conducted a study in which observers were required to watch a model practicing three variations of a timing task in a random or blocked schedule. The results of an immediate retention test revealed that both random physical practice and the observation of a random practice model resulted in the better acquisition of the task than a schedule of blocked physical practice or of blocked observation (see also Wright, Li, & Coady, 1997 for a similar observation). Concerning the effects of the amount of practice, Blandin and Proteau (1997) showed that increasing the number of observation trials benefited performance of a timing task, as was seen with physical practice.

All the above results suggest that variables affecting learning through physical practice tend to affect observational learning in a similar way. This supports the proposition that similar cognitive processes are involved in both observational and physical practice conditions.

Finally, recent results have shown that the intent to imitate/reproduce a task following observation could have an important impact on observational learning. Using positron emission tomography (PET), Decety et al. (1997) instructed participants to observe a sequence of hand movements with one of two goals: to be able to recognize or imitate these movements later. They found that observation with the intent to imitate increased activity in the regions involved in the planning and in the generation of actions, whereas observation with the intent to recognize activated memory-encoding structures. Thus, neural substrates responsible for the planning and execution of motor programs are activated during observation only when the goal is to reproduce the observed action (Decety & Grezes, 1999). This notion is consistent with the results of behavioral studies. For instance, Badets, Blandin, and Shea (2006) tested two groups of participants who observed a model practicing a timing task. Before observation, the participants in the first group were explicitly instructed that they would be required to perform the observed task as accurately as possible during a delayed retention test (i.e., observation with intention).

Observers in the second group were instructed that they would be required to come back to the laboratory on the following day to describe the task as accurately as possible (i.e., observation without intention). The results of the retention test revealed that the "observation with intention" group outperformed the other group of observers on the relative timing of the task. This suggests that observational learning is enhanced by the intention to reproduce the observed task. In a different study, Badets, Blandin, Bouquet, and Shea (2006) showed that the intention superiority effect holds for observational practice as well as for physical practice.

Looking for an optimal model

The primary goal of the studies presented in this thesis was to determine the type of model and the conditions of observation that are best suited to promote learning of a motor task.

Study 1. Different types of models have been used to facilitate motor skill learning. It has been shown that observing an expert model facilitates learning of a motor skill (e.g., Al-Abood, Davids, & Bennett, 2001; Bird & Heyes, 2005; Heyes & Foster, 2002; Hodges, Chua, & Franks, 2003; Lee, Swinnen, & Serrien, 1994; Martens et al., 1976; McCullagh et al., 1989). Given that this type of model represents a near perfect example of what to do (or an appropriate movement strategy [Bandura, 1977, 1986]), it presumably enables the observer to form an accurate representation or perceptual blueprint (Sheffield, 1961) of the observed task. However, because there is little error information to process when observing an expert model, the observer might not be actively involved in the "error detection and correction" processes. In that regard, other observational learning studies have used a novice model who does not display full mastery of the skill but rather is engaged in a learning process (Black & Wright, 2000; Blandin & Proteau, 2000; Buchanan & Dean, 2010; Buchanan, Ryu, Zihlman, & Wright, 2008; Lee & White, 1990; Mattar & Gribble, 2005; McCullagh & Caird, 1990; McCullagh & Meyer, 1997; Pollock & Lee, 1992). These studies were based on Adams' (1986) proposition that watching a model who is learning the task can help the observer associate different movement patterns with different outcomes (i.e., success or failure). Moreover, because a beginner is prone to commit more frequent and larger errors than an expert, an observer stands a better chance of detecting these errors and of learning from them (Blandin & Proteau, 2000). Therefore, although the observer does not have access to a good example of what to be done when observing a beginner model, he or she is able to learn the task, presumably through the development of error detection and correction mechanisms. This is consistent with motor learning theories that underline the information processing aspects of motor skill acquisition and the importance of movement corrections based on knowledge of movement errors (Adams, 1971; Schmidt, 1975).

Despite the potential differences between what could be learned while observing an expert or a novice model, several studies have shown that observation facilitates the learning of a new motor skill without significant differences related to the type of model observed. For example, Weir and Leavitt (1990) directly compared participants who watched filmed demonstrations of either an expert or a novice dart player prior to physically practicing the same task themselves. They found no differences related to the model's skill level. These results were replicated by Pollock and Lee (1992), who studied the effects of the model's skill level on the learning of a computer tracking game, and by Blandin and Proteau (2000, Experiment 1), who used a four-segment timing task. These results suggest that although expert and novice models presumably lead to the development of different processes, they may each have their own benefits.

Thus, although the observation of expert models may provide a good basis for the development of a movement representation, it offers a weaker basis for the evaluation of movement error. In contrast, observing a novice model may enable the observer to develop error detection and correction mechanisms, but it may not be optimal for the development of a movement representation or "perceptual blueprint." We reasoned that observing both types of models and thus being able to compare expert and novice performances would lead to better learning of the task than observation of a single type of model. To our knowledge, the efficacy of mixed observation (combination of novice and expert models) to promote motor learning has never been evaluated. In addition to the development of different and complementary mechanisms, observing more than one model would provide the observer with a form of variable/random practice, which has been argued to promote motor skill acquisition (Blandin et al., 1994; Buchanan & Dean, 2010; see also Hall & Magill, 1995; Lee, Magill, & Weeks, 1985; Shea, Lai, Wright, Immink, & Black, 2001; Van Rossum, 1990; Wright, Magnuson, & Black, 2005). Thus, in the first study described in this thesis, we wanted to determine whether the mixed observation of expert and novice models better promotes motor skill learning than observation of either an expert or a novice model. If so, we also sought to determine whether there is a type of novice model that optimizes learning within a mixed schedule of observation.

Study 2. Another factor influencing the attributes of an optimal model could be his or her handedness. Most individuals (about 90%; Annett, 1978) show a strong preference to use their right hand (e.g., right-handedness), which is associated with left-cerebral dominance, although about 10% of the population are left-handed (Ida & Mandal, 2003). Therefore, in many real-life situations, one may observe an opposite-handed model, like when a left-handed trainer shows a right-handed pupil how to "putt or drive" a golf ball.

Brain imaging studies have found that handedness influences neural correlates of action execution (e.g., Kim et al., 1993; Kloppel et al., 2007) as well as action observation (Wakita & Hiraishi, 2011; Willems & Hagoort 2009). Using near-infrared spectroscopy (NIRS), Wakita and Hiraishi (2011) recorded the activity of the Broca area (BCA) in left hemisphere while right-handed participants observed chopstick use performed by a model using either the right hand (i.e., same-handed model) or the left hand (i.e., opposite-handed model). The results showed that the BCA responded more strongly during observation of the right-handed than the left-handed movements, suggesting that the observation of actions generates action planning based on the observer's own motor representation. If so, it is hypothesized that observation of a same-handed model would result in better learning of a motor task in comparison with observation of an opposite-handed model.

In addition, a model may be observed from different viewpoints. The observer may face the trainer (3rd-person observation) or be located such that he or she has the same perspective as the trainer (1st-person observation). Most observational learning studies have used a first-person viewpoint (e.g., Blandin et al., 1999; Blandin & Proteau, 2000; Mattar & Gribble, 2005) because it requires less transformation of the information than a third-person viewpoint. This is consistent with recent findings of brain imaging studies. In a recent functional magnetic resonance imaging (fMRI) study, Jackson, Meltzoff, and Decety (2006) measured the cerebral activation in participants observing video clips of simple hand and foot actions, either from the perspective of the participant (1st-person perspective) or from a frontal view as though watching someone else (3rd-person perspective). Functional imaging results revealed that action observation in a first-person perspective, compared with a third-person perspective, increased activation in the left sensory-motor cortex. In the same vein, Pilgramm et al. (2010) examined how the visual viewpoint (1st vs. 3rd person) affects the activation of the human premotor cortex and showed higher activation for this area of the brain in a first-person condition. Moreover, a transcranial magnetic stimulation (TMS) study by Alaerts, Heremans, Swinnen, and Wenderoth (2009) showed that, in right-handed participants, observing right-hand actions from an egocentric (first-person) perspective elicited higher responses in the left primary motor cortex than observing actions from an allocentric (third-person) perspective. Thus, these findings suggest that a first-person observation is more extensively matched to the sensory-motor system than the third-person observation.

It is plausible that the larger activation in motor-related areas of the left hemisphere noted when observation took place from a first- rather than from the third-person perspective in the previously mentioned studies could have resulted from the fact that action representations are differently lateralized for the 1st- and 3rd-person observation viewpoints. Recent research indicates that observing a left- or right-hand movement from a first-person perspective resulted in larger activation of the contralateral motor cortex, as is the case when one performs the observed task (Shmuelof & Zohary, 2006, 2008). However, when observation was from a third-person perspective, a larger activation of the ipsilateral portion of the motor cortex was revealed (Alaerts et al., 2009; Hesse, Sparing, & Fink, 2009; Shmuelof & Zohary, 2008). That is, observing a right-handed action increased activity in the right hemisphere and vice versa. Therefore, it appears that learning a motor skill might be facilitated when observing a same-handed trainer from a first-person perspective but an opposite-handed trainer from a third-person perspective. However, this larger activation of different brain regions does not necessarily mean behaviorally significant differences in the learning of a complex motor task. The goal of the second study of this thesis was to determine whether a same-handed or an opposite-handed model would better promote learning and whether this would be mediated by the observer's perspective.

Study 3. In the third study presented in this thesis, we investigated the effects of live versus video presentation techniques for the observational learning of motor skills. Empirical evidence shows that an individual can learn a motor task through observation of a live model (e.g., Badets, Blandin, Wright, & Shea, 2006; Bird & Heyes, 2005, Experiment 1; Black & Wright, 2000; Blandin et al., 1994; Buchanan & Dean, 2010; Buchanan & Wright, 2011; Heyes & Foster, 2002; Pollock & Lee, 1992) or a video presentation of the model performing the task (e.g., Bird & Heyes, 2005, Experiments 2 and 3; Blandin et al., 1999; Blandin & Proteau, 2000, Experiment 1; Hayes, Elliott, & Bennett, 2010; Horn, Williams, & Scott, 2002; Osman, Bird, & Heyes, 2005; Trempe et al., 2011). However, neuroimaging studies suggest that live and video observation are processed differently in the brain. For example, Perani and colleagues (2001) proposed that the perception of action maps onto existing action representations only during live observation. Observers in virtual-reality and video conditions do not access the full motor knowledge that is available to the action observation network (Perani et al., 2001). Interestingly, magnetoencephalographic (MEG) recordings have revealed a stronger activation of the primary motor cortex in adult participants observing hand actions in a live condition rather than in a video condition (Jarvelainen, Schurmann, Avikainen, & Hari, 2001; see Shimada & Hiraki, 2006 for similar results in children). This suggests that live observation might result in better learning compared with video observation.

At the behavioral level, to the best of our knowledge, there have been only two published studies comparing the effectiveness of live vs. video observation in adult participants (Kernodle, McKethan, & Rabinowitz, 2008; Reo & Mercer, 2004). Neither reported a significant difference between the two modes of observation, which is inconsistent with the predictions of the aforementioned brain imaging studies. However, in both of these studies, a mixed schedule of observation and physical practice was used for the acquisition of the experimental tasks (i.e., blocks of physical practice trials were interspersed with blocks of observation trials during acquisition of the task). It is possible that interspersing observation with physical practice washed out the potential differences between the live and video conditions of observation. The first goal of our third study was to determine whether live observation better promotes learning of a complex multi-segment timing task than video observation. Our second goal was to determine whether live vs. video observation would be mediated by the observer's perspective.

Chapter 2 : Study 1

Learning through observation:

A combination of expert and novice models favors learning

Hassan Rohbanfard and Luc Proteau

Département de kinésiologie, Université de Montréal

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Abstract

Observation of an expert or novice model promotes the learning of a motor skill. In two experiments, we determined the effects of a mixed observation schedule (a combination of expert and novice models) on the learning of a sequential timing task. In Experiment 1, participants observed a novice, expert, or both novice and expert models. The results of retention/transfer tests revealed that all observation groups and a physical practice group learned the task and outperformed a control group. However, observing a novice model was not as effective as observing expert and mixed models. Importantly, a mixed schedule of novice and expert observation resulted in a more stable movement time and better generalization of the imposed relative timing pattern than observation of either a novice or expert model alone. In Experiment 2, we aimed to determine whether a certain type of novice performance (highly variable, with or without error reduction with practice) in a mixed observation schedule would promote improved motor learning. The observation groups performed as well as a physical practice group and significantly better than a control group. No significant difference was observed with the type of novice model used in a mixed schedule of observation. The results suggest that mixed observation provides an accurate template of the movement (expert observation) that is enhanced when contrasted with the performance of less successful models.

Keywords: Observational learning, motor learning, action observation network, timing task

Learning through observation:

A combination of expert and novice models favors learning

Observation contributes to the learning of a wide variety of tasks (see Ferrari, 1996; Hodges, Williams, Hayes, & Breslin, 2007; McCullagh, Weiss, & Ross, 1989; Vogt & Thomaschke, 2007; Wulf & Mornell, 2008, for reviews on observational learning). At the behavioral level, research indicates that observation facilitates motor learning because it enables an individual to determine the key spatial and/or temporal features of the task, which removes the need to create a cognitive representation of the action pattern through trial and error (Blandin, Proteau, & Alain, 1994; Buchanan & Dean, 2010; Carroll & Bandura, 1982; Pollock & Lee, 1992; Schmidt & Lee, 2005; Scully & Newell, 1985). This is supported by recent neuroimaging studies indicating that an "action observation network" (including the premotor cortex, inferior parietal lobule, superior temporal sulcus, and supplementary motor area) engages the observer in processes similar to those involved in performing the physical practice (Buccino et al., 2001; Cisek & Kalaska, 2004; Cross, Kraemer, Hamilton, Kelley, & Grafton, 2009; Dushanova & Donoghue, 2010; Frey & Gerry, 2006; Gallese, Fogassi, Fadiga, & Rizzolatti, 2002; Grafton, Fadiga, Arbib, & Rizzolatti, 1997).

In the present study, we sought to determine the model that most effectively promotes learning a motor skill. It has been shown that observing a skilled model facilitates task learning (Al-Abood, Davids, & Bennett, 2001; Bird & Heyes, 2005; Heyes & Foster, 2002; Hodges, Chua, & Franks, 2003; Lee, Swinnen, & Serrien, 1994; Martens, Burwitz, & Zuckerman, 1976; McCullagh et al., 1989). Because this type of model represents a correct example of how to perform a task (or an appropriate movement strategy), it presumably enables the observer to form a “perceptual blueprint” of the task to be learned (Sheffield, 1961). This blueprint serves as a standard of reference that participants compare their performance against (Bandura, 1986). However, because learning is a problem-solving process, novice models have also been used successfully for task learning (Black & Wright, 2000; Buchanan & Dean, 2010; Buchanan, Ryu, Zihlman, & Wright, 2008; Hayes et al., 2010; Lee & White, 1990; McCullagh & Caird, 1990; McCullagh & Meyer, 1997; Pollock & Lee, 1992). These studies are consistent with Adams’ (1986) proposition that watching a model learning the task can help the observer associate different movement patterns with different outcomes (i.e., success or failure). Moreover, because a beginner is prone to commit more frequent and larger errors than an expert (Blandin & Proteau, 2000) and to try different movement strategies (Buchanan & Dean, 2010), an observer has a better chance of detecting these errors or changes in strategy and learn from them.

Despite the potential differences between what could be learned while observing a skilled versus a novice model, several studies have shown that observation facilitates learning a new motor skill without significant differences related to the type of model observed. For example, Weir and Leavitt (1990) compared participants who watched filmed demonstrations of either a skilled or a novice dart player prior to physically practicing the same task, and the authors found no differences in performance between the two groups. These results were replicated by Pollock and Lee (1992), who studied the effects of the model's skill level on learning a computer tracking game, and by Blandin and Proteau (2000, Experiment 1), who used a four-segment timing task. These data indicate that expert or novice observation might have a similar impact on learning, despite presumably developing different cognitive processes.

Experiment 1

If the observation of expert and novice models leads to the development of different processes, they should have enhanced effects on observational learning. Thus, observing both types of models and comparing expert and novice performances should result in better task learning than observing either a skilled or a novice model alone. To our knowledge, the efficacy of mixed observation (a combination of novice and expert models) to promote motor learning has never been evaluated[2]. As alluded to above, if it is true that observing an expert model favors the development of a motor schema of the task to be performed (Blandin, Lhuisset, & Proteau, 1999; a perceptual blueprint in Sheffield's terminology) and that watching a novice model helps to detect errors and determine how to correct them, then observing both models should lead to superior task learning compared to the observation of a single model. Therefore, the primary goal of the current experiment was to determine whether mixed observation of both expert and novice models promotes motor skill learning more effectively than observation of either an expert or novice model alone.

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[2] Depending on task difficulty and the number of practice trials performed, it could be argued that observation of a novice model provides information relative to a novice performance in the early stages of training and a near expert performance at the end of the model's training session.

Participants were required to observe or physically practice a four-segment timing task (as shown in Figure 1). Participants were asked to complete each segment of the task in an intermediate time (IT) of 300 ms, leading to a total movement time (TMT) of 1200 ms. Participants in the observation groups observed an expert model, a novice model, or a combination of trials performed by expert and novice models. It was hypothesized that participants in all observation groups would outperform participants from a no-practice control group. In addition, we speculated that if the observation of a combination of different model types enhanced task learning compared to the observation of either a novice or expert model alone, participants in the observation-mixed group would outperform participants in the two other observation groups (observation-novice and observation-expert groups).

In a pilot study, we determined the naturally emerging relative timing (Collier & Wright, 1995) in individuals who physically practiced the experimental task with their dominant (right) hand. Three participants who did not take part in the present study were asked to complete the task in a TMT of 1200 ms for 60 trials. No IT constraints were imposed. Participants received feedback on the TMT only following each trial. Completing 20 practice trials allowed participants to approach the TMT goal of 1200 ms. Data from the remaining forty trials revealed a stable relative timing pattern both within individuals and among different participants. On average, participants used a relative timing of 17.2%, 29.0%, 23.2% and 30.6% to complete the first, second, third and fourth segments of the experimental task, respectively (within- and between-participant variability fluctuated between 1.0% and 2.4%; see Blandin et al., 1999 for a similar observation). In the present study, participants were asked to perform each segment of the task in the same intermediate time (see below). Therefore, the task required participants to modify their naturally emergent relative timing pattern for this task. The learning of a new relative timing pattern was achieved if participants could maintain the pattern in a transfer test requiring task completion within a different TMT than previously observed.

Because a previous study found that observation alone does not lead to the optimal learning of a spatio-temporal task (Blandin et al., 1999), participants physically practiced the task following observation to determine the joint effects of different schedules of model observation and physical practice on motor task learning. It has been suggested that the physical practice trials allow the observers to refine the cognitive representation developed through observation (Bandura, 1986), presumably because response-produced sensory feedback engages the learner in processes that are not utilized during observation (Shea, Wright, Wulf, & Whitacre, 2000; Weeks & Anderson, 2000; Trempe, Sabourin, Rohbanfard, & Proteau, 2011). The joint effects of observation and physical practice were evaluated in 10-min and 24-hr delayed retention and transfer tests.

Methods

Participants

Sixty self-declared right-handed students (34 women) from the Département de kinésiologie at the Université de Montréal took part in this experiment. They were paid $15 CDN for their time. They had normal or corrected-to-normal vision, no prior experience with the task or apparatus used in this experiment. Participants completed and signed an individual consent form prior to participation. The Health Sciences Ethics Committee of the Université de Montréal approved this experiment.

Apparatus and task

The apparatus was similar to that used by De Jaeger and Proteau (2003). As illustrated in Figure 1, the apparatus consisted of a wooden base (45 × 54 cm), three wooden barriers (11 × 8 cm), and a starting button embedded in a target (11× 8 cm). The distance between the starting button and the first barrier was 15 cm. The distances of the remaining three segments of the task were 32 cm, 18 cm and 29 cm, respectively, for an overall movement of 94 cm. The barriers were placed perpendicular to the wooden base at the beginning of each trial, yielding a closed microswitch circuit. All of the microswitches were connected to a computer via the I / O port of an A-D converter (National Instruments), and a millisecond timer was used to record total movement time (TMT) as well as the time required to complete each segment of the task (intermediate times; ITs).

The movement pattern used in the present study is also illustrated in Figure 1. The participant sat close to the starting position in front of the apparatus. Then, from the starting button, the participant was asked to sequentially knock down the first, second, and third barriers (thus releasing the microswitches) and finally hit the target in a clockwise motion. Each segment of the task had to be completed in an intermediate time (IT) of 300 ms, for a total movement time of 1,200 ms (TMT). The movement pattern, ITs and TMT were illustrated on a poster located directly in front of the apparatus during all experimental phases.

Experimental phases and procedure

Once 60 individuals had accepted to take part in the present study, they were randomly assigned to one of the five groups of 12 participants: physical practice (6 women), observation-novice (7 women), observation-expert (7 women), observation-mixed (7 women), and control (7 women). Participants in the physical practice group completed the experiment first; the remaining five groups were tested in succession. We chose to study the effects of different types of models on observational learning using a between-subject design (one group for each condition) to prevent any potential learning effects transferred from one condition to another (Cross et al., 2009).

All groups performed six experimental phases (see Table 1). All participants received verbal instructions regarding TMT and ITs before the first experimental phase. During the first phase (pre-test), subjects participated in 20 trials without knowledge of results (KR) on the TMT and ITs. In the second phase (acquisition 1; ACQ1), each participant in the physical practice group practiced the task for 60 trials. After each trial, they received KR on the TMT and ITs on a computer screen. They were filmed by a camera located above their right shoulder that showed their right arm at rest, prior to movement initiation, and while performing the experimental task. During this phase, participants in the three observation groups watched a video presentation of a novice, an expert or trials performed by both a novice and an expert model performing the same task. Observation consisted of 60 trials with KR concerning the model's performance (both TMT and ITs) after each trial. KR was presented in the same format as for the physical practice group.

The novice model was a male participant from the physical practice group. He was chosen due to his steady improvement in his IT with practice. We edited the video of this participant to eliminate undue inter-trial delay and showed all 60 trials performed by this novice model to the observation-novice group. One of the authors (H.R.) served as the expert model. He had practiced the task for 3,000 trials over a 15-day period, and he was filmed while performing his last 60 practice trials. This film was edited so that the inter-trial delays matched those of the edited video of the novice model and was presented to the observation-expert group. Observers could easily determine that both the novice and expert models were male. The TMTs and relative timing performances of the 60 trials observed by the observation-novice and observation-expert groups are illustrated in Figure 2. The observation-mixed group watched a film showing 30 trials performed by the novice model and 30 trials performed by the expert model. We picked the odd numbered trials filmed for each model (trials 1, 3, 5 … 59). This approach permitted us to show the progression in performance of the novice model, whereas while the performance of the expert model was very stable across trials. The model was alternated every 5 trials (i.e., novice: trials 1-5 and expert: trials 6-10). The participants in the mixed-observation group were informed that they would observe both an expert and a novice model. Prior to each set of 5 trials, they were also reminded about which model they would be observing. Participants in the control group did not practice during this phase. Instead, they read a newspaper or magazine provided to them for the same duration as the observation or physical practice for the other groups (approximately 10 min).

The third experimental phase was an immediate retention/transfer test composed of 40 trials (20 retention and 20 transfer) with no KR for any participant. In the retention trials, as in ACQ1, participants were asked to complete each segment of the task in 300 ms for a TMT of 1200 ms. For the transfer trials, participants were asked to complete the task in 1500 ms while keeping the same relative timing as before (25% of TMT or 375 ms for each segment of the task). If practice led to the learning of relative timing, participants were expected to perform equally well in the retention and transfer tests.

The immediate retention/transfer test was followed by a second acquisition phase (ACQ2) consisting of 60 physical practice trials with KR for all groups except for the control group, whose members resumed reading for a period of 10 min. Finally, all participants performed two delayed retention/transfer tests (10 min and 24 hr after ACQ2), each consisting of 40 trials (20 retention and 20 transfer trials) with no KR. Performance on these tests determined the joint effects of observation and physical practice on task learning.

Data analysis

The absolute value of each participant's constant error (|CE|, the constant error indicates whether a participant undershot [negative value] or overshot [positive value] the total movement time) and variable error (VE, or within-participant variability) of total movement time were calculated to determine the accuracy and consistency of participant movements, respectively. For intermediate times, we computed the root mean square error (RMSE), which presents in a single score how much each participant deviated from the prescribed relative timing pattern. For each trial:

$RMSE = \sqrt{\sum_{Segment1}^{Segment4}\left(\frac{(ITi - target)^2}{4}\right)}$, where ITi represents the intermediate time for segment i and *target* is the goal movement time for each segment of the task (i.e., 300 ms for the retention trials and 375 ms for the transfer trials).

The data from all phases were regrouped into blocks of five trials. To determine the efficacy of different observation regimens on learning, the data for each dependent variable were submitted individually to an analysis of variance (ANOVA) comparing the 5 groups (physical practice, observation-novice, observation-expert, observation-mixed, and control) x 4 phases (pre-test, immediate retention, retention 10-min, and retention 24-hr) x 4 blocks of trials with repeated measures on the last two factors.

Furthermore, to determine whether the observation of different models facilitated the acquisition of the task through physical practice, the ACQ2 data for the three observation groups and the physical practice group were contrasted in a 4 groups (physical practice, observation-novice, observation-expert and observation-mixed) x 12 blocks of trials (trials 1-5, 6-10, 11-15, …56-60) ANOVA with repeated measures on the block factor.

Finally, to determine whether a practice regimen favored the learning of a newly imposed relative timing routine over other practice schedules, the data collected in the transfer tests were submitted to an ANOVA comparing 5 groups x 3 phases (immediate transfer, 10-min transfer, and 24-hr transfer) x 4 blocks with repeated measures on the last two factors[3].

Before computing the different ANOVAs, three specific assumptions of the ANOVA were tested. The z scores of the skewness and kurtosis values were calculated to test the normality of the distribution (Tabachnick & Fidell, 2007). To verify the homogeneity of variances, Hartley's F_{max} test was used. Finally, the degrees of freedom were adjusted as suggested by Greenhouse and Geisser (1959) when Mauchly's test of sphericity was significant. However, the original degrees of freedom are presented when the effects were significant following the Greenhouse-Geisser correction. Any significant interactions were then separated into their constituent simple main effects. All significant main effects and simple main effects involving more than two means were broken down using LSD post hoc procedures. All effects were deemed significant if $p < 0.05$. One participant from the control group was excluded from all analyses because his performance times (IT and TMT) in all test phases were worse than his group's mean by more than 2.5 standard deviations (SD).

Results

Total movement time

Retention phases. The results of the ANOVA computed on |CE| revealed significant main effects of Group (F (4, 54) = 13.67), Phase (F (3, 162) = 59.44), and Block

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[3] For all dependent variables, we also computed additional analyses in which the performance of the different groups was contrasted independently between (a) the pre-test and immediate retention test and (b) the 10-min and the 24-hour retention tests. In addition, in the analyses contrasting the 10-min and the 24-hour retention tests, the control group was included or was not included in independent sets of analyses. The results of all of these analyses did not significantly change the findings reported in the main text. Therefore, we opted to present the data using the more economical format.

(F (3, 162) = 3.46) as well as a significant Phase x Group interaction, F (12, 162) = 4.26. The breakdown of the interaction revealed the following effects. As illustrated in Figure 3 (upper left panel), there were no significant differences between groups in the pre-test ($F<$ 1), confirming that the groups did not differ before training. For the remaining three phases, the control group had a significantly larger |CE| than the four remaining groups, which did not differ significantly from one another (F (4, 54) = 22.60, 19.19, and 14.33 for the immediate, 10-min, and 24-hr retention tests, respectively). Post hoc comparisons on the Block main effect revealed that participants had a significantly larger |CE| in block 4 than in blocks 1 to 3 and in block 3 compared with block 2 (139 ms, 137 ms, 143 ms, and 148 ms for blocks 1-4, respectively).

The ANOVA computed on VE (see Figure 3, middle left panel) revealed significant main effects of Group (F (4, 54) = 4.20), Block (F (3, 162) = 63.51), and Phase (F (3, 162) = 16.79) and a significant Phase x Block interaction (F (9, 486) = 18.73). Post hoc comparisons revealed that the observation-novice group had a significantly larger VE (60 ms) than the remaining groups, which did not differ significantly from one another (47 ms, 48 ms, 52 ms, and 46 ms for physical practice, control, observation-expert, and observation-mixed groups, respectively). The breakdown of the Phase x Block interaction revealed that participants had a significantly larger VE in block 1 than in the three remaining blocks, which did not differ significantly in the pre-test, immediate RET or RET24. However, there were no significant differences between blocks in RET10.

Taken together, the results presented above suggest that participants became more proficient at completing the task in the prescribed movement time through both observation and physical practice. However, observation of a novice model led to more variable performance than that noted for all other groups.

Transfer phases. The ANOVA on |CE| revealed significant main effects of Group (F (4, 54) = 19.90) and Block (F (3, 162) = 6.23) and a significant Phase x Group (F (8, 108) = 2.06) interaction. The breakdown of this interaction (see Figure 3, upper right panel) revealed that all experimental groups significantly outperformed the control group in all phases (p values < .001). In addition, the observation-mixed group had a significantly smaller |CE| compared to the observation-novice group (p = .043) in immediate TR and compared to the physical practice group in TR24 (p = .047). No other comparison was significant (ps > .05). Post hoc comparisons on the Block main effect revealed that participants had a significantly larger |CE| in block 1 than in the remaining blocks, which did not differ significantly from one another (176, 159, 152, and 157 ms for blocks 1-4, respectively).

The |CE| results indicate that observation per se (immediate transfer) resulted in a better generalization of TMT following mixed observation than observation of a novice model. In addition, a schedule of mixed observation followed by physical practice resulted in a significantly better generalization of TMT than a schedule of physical practice alone.

The ANOVA on VE (see Figure 3, middle right panel) only revealed significant main effects of Phase (F (2, 108) = 12.74) and Group (F (4, 54) = 4.52). Post hoc comparisons on the Phase main effect revealed that VE significantly decreased from one experimental phase to the next (68 ms, 61 ms, and 56 ms for immediate TR, TR10, and TR24, respectively). Post hoc comparisons of the Group main effect revealed that the observation-novice group had a significantly larger VE than the control group (p = .004). It should be noted that, considering the large |CE| reported for the control group, a low VE for the control group indicates that participants were consistently wrong.

Moreover, although the control group (55 ms) did not differ significantly from the other two observation groups (expert and mixed) or the physical practice group, the observation-mixed group (52 ms) performed significantly better than the observation-novice, observation-expert, and physical practice groups (VE = 65 ms, 72 ms, and 66 ms, for the physical practice, observation-novice, and observation-expert groups, respectively). The results of VE indicate that when participants were transferred from the practiced TMT to a different one, mixed observation resulted in lower variability than physical practice or observation of either novice or expert models.

Intermediate times

Retention phases. The results of the ANOVA computed on RMSE revealed significant main effects of Group (F (4, 54) = 12.47), Phase (F (3, 162) = 122.83) and Block (F (3, 162) = 11.29) and a significant Phase x Group interaction (F (12, 162) = 8.22). As illustrated in Figure 3 (lower left panel), the breakdown of the interaction did not reveal any significant group differences in the pre-test (F< 1). In immediate RET, however, the control group had a significantly larger RMSE than the four other groups (F (4, 54) = 12.75). Moreover, the physical practice group outperformed the observation-novice (p = .004) and the observation-expert groups (p = .063) but not the observation-mixed group (p = .489), whereas the observation-mixed group outperformed the observation-novice group (p = .027). In both the 10-min and the 24-hr retention tests, the control group showed a significantly larger RMSE than the remaining four groups, which did not differ significantly from one another ($\underline{F}$ (4, 54) = 25.68 and 22.48, respectively). Post hoc comparisons on the Block main effect revealed that participants had a significantly larger RMSE in block 1 than on the three other blocks, which did not differ significantly from one another (67, 63, 63, and 64 ms for blocks 1-4, respectively). In short, only the observation of mixed models permitted participants to perform ITs as accurately as physical practice in immediate retention trials. Physical practice following observation permitted all groups of observers to perform as well as the physical practice group in the delayed retention tests.

Transfer phases. The ANOVA revealed significant main effects of Group ($\underline{F}$ (4, 54) = 25.12), Phase ($\underline{F}$ (2, 108) = 20.49) and Block ($\underline{F}$ (3, 162) = 3.73) and a significant Group x Phase interaction ($\underline{F}$ (8, 108) = 5.30). The breakdown of the interaction (see Figure 3, lower right panel) revealed that all observation groups and the physical practice group had significantly smaller RMSE than the control group in all transfer tests ($\underline{F}$ (4, 54) = 13.23, 22.47, and 32.14 for immediate TR, TR10, and TR24, respectively). In addition, the observation-novice group had a significantly larger RMSE in immediate TR than the remaining three experimental groups, whereas the observation-mixed group had a significantly smaller RMSE in TR24 than the remaining three experimental groups. Finally, post hoc comparisons of the Block main effect again revealed that participants had a significantly larger RMSE in block 1 than in the remaining blocks, which did not differ significantly from one another (74, 71, 70, and 71 ms for blocks 1-4, respectively). Thus, observation per se, like physical practice, resulted in reduced RMSE compared to no practice (i.e., control group). However, observation of a novice model resulted in larger

RMSE values compared to physical practice or other observation regimens. Finally, mixed observation followed by physical practice resulted in a lower RMSE in the 24-hour transfer test than all other practice regimens used in this experiment.

Acquisition data

The effects of different observation schedules on learning TMT and ITs were further investigated by contrasting the performance of the three observation groups with the physical practice group in ACQ2. The results of the ANOVA computed on |CE| revealed significant main effects of Block ($\underline{F}$ (11, 484) = 10.81) and Group ($\underline{F}$ (3, 44) = 3.53) and a significant Block x Group interaction ($\underline{F}$ (33, 484) = 1.76). The breakdown of the interaction revealed the following effects (see Figure 4, upper panel). On blocks 1 and 11, the observation-novice group had a significantly larger |CE| than the other groups, which did not significantly differ from one another. In block 8, the physical practice and observation-mixed groups outperformed the observation-novice group. The four groups did not differ significantly from one another for the remaining blocks.

Concerning VE, the results of the ANOVA revealed significant main effects of Block ($\underline{F}$ (11, 484) = 10.72) and Group ($\underline{F}$ (3, 44) = 7.28). Post hoc comparisons of the Block main effect indicated that VE decreased during physical practice with KR. Interestingly, post hoc tests on the Group main effect revealed that the physical practice and observation-mixed groups, which did not significantly differ from one another, had a significantly smaller VE than the observation-novice and observation-expert groups. Additionally, the observation-expert group had a significantly smaller VE than the observation-novice group (VE = 51 ms, 72 ms, 61 ms, and 50 ms, for the physical practice, observation-novice, -expert, and -mixed groups, respectively).

The ANOVA computed on RMSE revealed significant main effects of Group ($\underline{F}$ (3, 44) = 2.84) and Block ($\underline{F}$ (11, 484) = 23.05). Post hoc comparisons revealed that RMSE decreased during physical practice with KR. In addition, the observation-novice group had a significantly larger RMSE than the other groups, which did not differ significantly from one another (RMSE = 37 ms, 44 ms, 38 ms, and 36 ms for the physical practice, observation-novice, -expert, and -mixed groups, respectively).

Taken together, the results of the present section indicate that mixed-observation enabled participants to more reliably complete their movements in the allotted movement time (smaller VE) than observation of either a novice or expert model alone. Moreover, observation of a novice model resulted in larger relative timing errors (RMSE) compared with the other observation groups.

Discussion

Our primary goal was to determine whether a mixed observation schedule results in better learning of a multi-segment timing task than the observation of either expert or novice models alone. In agreement with previous research (Blandin et al., 1999; Blandin & Proteau, 2000; Lee & White, 1990; McCullagh & Meyer, 1997; Pollock & Lee, 1992), we found that observation led to immediate benefits regardless of the model. The three groups of observers not only out-performed the control group on both TMT and IT in the immediate retention test, but they also out-performed the control group in the immediate transfer test, indicating some generalization of the benefits of observation to a different TMT.

However, observing an expert model or a combination of both models resulted in better task learning compared with the observation of a novice model only. In all retention tests, the observation-novice group exhibited more variability in performance with regard to TMT than those in the observation-expert and observation-mixed groups. This result suggests that the observation of a novice model, whose performance is variable, causes inconsistency in the learner's performance. This trend likely results from trial-to-trial performance variations being more indirectly related to KR than is observed for the mixed and expert models.

Our finding that an expert model is preferable to a novice model supports some of the previous research (Blandin et al., 1999), but other reports (Blandin & Proteau, 2000; Pollock & Lee, 1992; Weir & Leavitt, 1990) found no difference in observing an expert or novice model. These contradictory findings could be related to the task complexity used in the different experiments. It seems that the advantage of observing an expert rather than a novice model is observed when the task to be learned is more complex. For example, in the present study and in a study by Blandin et al. (1999), the goal was to learn not only the TMT but also an arbitrarily chosen set of ITs, whereas in Blandin's and Proteau's work (2000, Experiment 1), participants were only required to learn the TMT.

Moreover, Pollock and Lee (1992) also reported that observing a novice model was as effective as observing an expert model. They interspersed the observation trials between physical practice trials, while in the present study, all observation trials were completed prior to any physical practice with KR. It could be that physically practicing the task between observation trials eliminated potential differences between the observation of an expert or a novice model. In support of this position, it should be noted that it took only five trials with KR for the observation-novice group to reduce their |CE| on TMT to the values obtained by the observation-expert group in ACQ2.

Although the performance of the observation-expert and observation-mixed groups did not differ significantly for some aspects of the task, the observation-mixed group out-performed the observation-expert group on some important features. Specifically, the results of the immediate retention test indicated that the observation-mixed group did not differ significantly from the physical practice group on intermediate task times. In addition, during ACQ2, when observers began physically practicing the task and receiving KR after each trial, the observation-mixed group had significantly lower inter-trial movement time variability than the other two observation groups. This result suggests that they were more skilled at using KR (i.e., less maladaptive corrections; Schmidt & Bjork, 1992) and/or that mixed observation led to a movement representation that was less susceptible to random fluctuations than other observation regimens. Lastly, when transferred to the 1500 ms task, the observation-mixed group outperformed the other two observation groups with regard to both the TMT and ITs. This result suggests that mixed observation resulted in the development of a more generalized movement representation than other types of observation. In our study, the observation-mixed group was never out-performed by the other observation groups for any dependent variable. These findings lead us to conclude that a mixed observation schedule more effectively promotes the learning/generalization of a complex sequential timing pattern than the observation of either novice or expert models alone.

Finally, concerning the joint effects of observation and physical practice (10-min and 24-hr retention tests), the results of the present study support previous studies (Blandin & Proteau, 2000) that demonstrate that a schedule of novice or expert model observation followed by physical practice was as effective as a 100% physical practice schedule. This conclusion is supported by the fact that the performances of the observation-novice, observation-expert and physical practice groups did not significantly differ in two delayed retention/transfer tests. However, it should be mentioned that the schedule of mixed observation and physical practice resulted in a better generalization of the sequential timing task than physical practice alone. This result is supported by the results of the 24-hr transfer test, in which the observation-mixed group out-performed the physical practice group on both the TMT and ITs. Because the performance of the physical practice group improved primarily during ACQ1 (Figure 4), it is tempting to conclude that 60 trials of physical practice with KR were enough to reach asymptotic performance, potentially explaining why one observation session followed by one physical practice session was as effective as two sessions of physical practice. However, two important aspects of the data argue against this conclusion. First, the performance of the expert model was largely better than that of the physical practice and observation groups (TMT very close to 1200 ms with small trial-to-trial variability and RMSE of ~ 8 ms; see Figure 2). Therefore, there was room for improvement. Second, if only 60 trials of physical practice had been sufficient to reach asymptotic performance, then all groups of observers and the physical practice group should have performed similarly in all retention and transfer tests. However, we observed differences between the groups. This result underlines the difference between performance and learning effects that has been extensively advocated in the motor learning literature (Schmidt & Lee, 2005).

Therefore, the results of this first experiment indicate that observing a combination of expert and novice models (mixed model) might promote task learning more effectively than other observation regimens. In Experiment 2, we sought to determine whether there is an optimal type of mixed model for promoting motor learning.

Experiment 2

The novice model used in the mixed model condition in Experiment 1 was a novice participant who gradually improved at performing the task during his first session of physical practice. This model presumably enabled the observers to pick up some necessary information on how to improve their performance. However, it might be more efficient to combine the expert model with a novice model who does not succeed in learning the task, allowing an observer to more easily contrast the novice model with the expert model throughout observation, or with a novice model who shows high trial-to-trial variability, given that variation in the performance of the novice has been shown to be effective for motor learning (Buchanan & Dean, 2010; Blandin et al., 1994). Thus, we combined three different novice models with the same expert model to determine whether a particular type of novice performance could optimize learning within a mixed observation schedule.

Methods

Participants

Sixty self-declared right-handed students (38 women and 22 men) from the Département de kinésiologie at the Université de Montréal participated in this experiment. None of the subjects participated in Experiment 1 or had prior experience with the task used in this experiment. All participants had normal or corrected-to-normal vision, signed a consent form, and were paid $15 CDN. The Health Sciences Ethics Committee of the Université de Montréal approved this experiment.

Apparatus, task, and procedure

The same apparatus and task from Experiment 1 were used. Twelve participants were randomly assigned to each of five groups: control (7 women), physical practice (7 women), and three different mixed observation groups (8 women per group). The mixed observation groups all observed the same expert model but differed in the type of novice performance observed. We used the same expert model as in Experiment 1. The novice models were chosen from among the participants of the physical practice group in Experiment 1. Because our goal was to determine which observation regimen would facilitate learning a new relative timing pattern, the chosen novice models (all men) differed primarily in this aspect of the task. For one group of observers (M↑), we used the novice model from Experiment 1 who had a large RMSE at the beginning of practice but steadily improved his performance across trials. For a second group (M→), the novice model had a moderate RMSE at the beginning of practice; however, his performance did not improve significantly with practice. The novice model for the third group (Mσ) demonstrated high trial-to-trial variability in performance. Again, observers could easily determine that the models were males. For each novice model, we selected 20 trials that were representative of his performance across the trials during physical practice. Figure 5 illustrates the TMT and RMSE performance of the selected trials for the novice and expert models.

There were six experimental phases: pre-test (PRT), acquisition 1 (ACQ1), immediate retention/transfer test (Imm. RET/ Imm.TR), acquisition 2 (ACQ2), 10-min retention/transfer test (RET10/TR10), and 24-hr retention/transfer test (RET24/TR24). Test phases were performed as described in Experiment 1. Participants observed or physically practiced 40 trials during ACQ1 and ACQ2. For the mixed observation groups, novice and the expert model observation was alternated every 5 trials during the first acquisition phase, starting with the novice model. Retention and transfer tests were as in Experiment 1. Individual data were screened as in Experiment 1. The data from one participant in the control group were withdrawn from all analyses because his performance (IT and TMT) in all test phases was worse than his group's mean by more than 2.5 SD.

Results

Total movement time

Retention phases. The results of the ANOVA computed on |CE| revealed significant main effects of Group ($\underline{F}$ (4, 54) = 4.44) and Phase ($\underline{F}$ (3, 162) = 43.44) and a significant Group x Phase interaction ($\underline{F}$ (12, 162) = 2.73). As illustrated in Figure 6 (upper left panel), the interaction revealed no significant differences between groups with regard to pre-test scores ($\underline{F}$ (4, 54) < 1). For the remaining phases, all three observation groups and the physical practice group did not differ significantly from one another but significantly outperformed the control group (F (4, 54) = 6.39, 12.77, and 10.59 for the immediate, 10-min, and 24-hr retention tests, respectively).

Concerning VE (see Figure 6, middle left panel), the results of the ANOVA revealed significant main effects of Phase (F (3, 162) = 12.89) and Block (F (3, 162) = 19.10) and a significant Phase x Block interaction (F (9, 486) = 8.27). The interaction revealed that in the pre-test, participants had a significantly larger VE in block 1 than in the three remaining blocks, which did not differ significantly from one another (F (3, 52) = 14.72). For the remaining three phases, there was no significant difference among blocks (all Fs< 1).

Transfer phases. Significant main effects of Phase (F (2, 108) = 6.88) and Group (F (4, 54) = 7.47) were noted for |CE|. Post hoc comparisons revealed that the control group had a significantly larger |CE| than the remaining groups, which did not differ significantly from one another (356, 165, 157, 175, and 170 ms for the control, PP, M→, Mσ, and M↑, respectively). In addition, |CE| significantly decreased from the immediate to both the 10-min and the 24-hr retention tests (234 ms, 184 ms, and 196 ms, respectively).

The ANOVA on VE revealed a significant main effect of Phase (F (2, 108) = 11.40). Post hoc comparisons revealed that VE decreased significantly from one experimental phase to the next (74 ms, 67 ms, and 60 ms for immediate, 10-min, and 24-hr transfer tests, respectively).

Intermediate times

Retention phases. The ANOVA computed on RMSE revealed significant main effects of Group (F (4, 54) = 8.80) and Phase (F (3, 162) = 99.81) and a significant Group x

Phase interaction ($\underline{F}$ (12, 162) = 4.64). As illustrated in Figure 6 (lower left panel), the interaction revealed no significant group differences in the pre-test ($\underline{F}$ (4, 54) < 1). For the remaining three phases, the control group had a significantly larger RMSE than the four other groups, which did not differ significantly from one another ($\underline{F}$ (4, 54) = 9.27, 24.39 and 19.99 for immediate, 10-min, and 24-hr retention tests, respectively). Figure 6 (lower left panel) also illustrates that all experimental groups exhibited significantly reduced RMSE from the pre-test to the other three experimental phases, whereas the control group did not. It is worth noting that going from the 10-min to the 24-hr retention test resulted in a significant increase of RMSE for the physical practice group but not for the three mixed-observation groups. This last result suggests that a schedule combining mixed observation and physical practice consolidates learning of intermediate times more effectively than a physical practice schedule.

Transfer phases. Significant main effects of Group ($\underline{F}$ (4, 54) = 15.59) and Phase ($\underline{F}$ (2, 108) = 28.53) and a significant Group x Phase interaction ($\underline{F}$ (8, 108) = 2.44) were noted. The interaction revealed that the control group performance did not differ significantly from one experimental phase to the next. However, all other experimental groups improved their performance from the immediate to the 10-min transfer test and remained unchanged thereafter ($\underline{F}$ (2, 53) = 3.54, 10.43, 10.57, 4.64, and 1.64 for PP, M→, Mσ, and M↑, and control groups, respectively; see Figure 6, lower right panel).

Discussion

The main goal of Experiment 2 was to determine whether there is an optimal type of novice performance to use in a mixed observation schedule. The results of the present experiment replicated the results of Experiment 1, indicating that mixed observation results in significant learning with regard to both TMT and IT and was as efficient as physical practice for learning/retention of the experimental task. However, there was no difference attributable to the type of mixed model observed. It appears that having observed expert and novice models in quick succession provided observers with enough information to learn the task. The ability to compare expert and novice performances, rather than the type of novice model, is likely the most critical determinant of the effectiveness of a mixed model. We will return to this point in the general discussion.

Concerning the joint effects of mixed observation followed by physical practice, the results of the present experiment did not replicate the unexpected finding of Experiment 1. In Experiment 1, a mixed observation schedule followed by physical practice resulted in improved transfer of both the TMT and ITs compared to a 100% physical practice schedule. However, the mixed observation groups and the physical practice group performed equally well in both 10-min and 24-hr retention/transfer tests on both the TMT and ITs in the present experiment. The performance of the physical practice group deteriorated significantly from the 10-min to the 24-hr retention test, whereas this trend was not observed for any of the three observation groups. Thus, the results of the present experiment concerning the joint effects of observation and physical practice concur with previous studies, indicating that a schedule of observation followed by physical practice could be as effective as a physical practice schedule alone (Blandin & Proteau, 2000; Deakin & Proteau, 2000). The retention results of the physical practice group and all observation groups (RMSE of 40-50 ms; see Figure 6) compared with the results of the expert model (RMSE of ~8 ms; see Figure 5) indicate that the similarity in performance following only physical practice or a combination of observation and physical practice did not result from a floor effect.

General discussion

In the present study, we sought to determine if a mixed schedule of expert and novice observation promotes the learning of a four-segment timing task more effectively than observation of either an expert or novice model alone. In addition, if a mixed observation schedule was more effective, we wanted to determine whether there is an optimal type of novice model for observation in a mixed observation schedule.

The results of the present study concur with previous studies that show that observation led to significant task learning (e.g., Badets, Blandin, & Shea, 2006; Hayes, Elliott, & Bennett, 2010; Heyes & Foster, 2002; Mattar & Gribble, 2005). An important new finding of the present study is that mixed observation of expert and novice models resulted in a better generalization of learning in both total and intermediate movement times compared with the observation of either type of model alone. Moreover, the learning of the experimental task did not differ significantly following physical practice or observation of a mixed model in either experiment (immediate retention/transfer tests). This finding differs from previous studies in which a few trials of physical practice followed by the knowledge of the results was required for observers to become as effective as the physical practice group (Blandin et al., 1999; Blandin & Proteau, 2000; Deakin & Proteau, 2000; Shea et al., 2000). Thus, it appears that a mixed observation schedule engaged the observer in processes that were more similar to those experienced during physical practice than observing either an expert or novice model alone. Expert model observation provided the observer with an accurate template for performing the task, which likely permitted participants to detect errors in the performance of the novice model and determine how to avoid/correct them. This comparison between what was needed for task performance and the typical errors of novice participants was not possible for observers of only an expert or novice model. The results of Experiment 2 indicate that it did not matter whether the novice model improved with practice or if his performance varied greatly from trial to trial.

In addition, it could be that solely observing expert models might not engage an individual as actively in information processing as mixed observation. Because observing an expert model for long series of trials results in repeated representations of near-perfect performance (see Figure 5) that show very little trial-to-trial variability, we speculate that the observation-expert group took part in a condition that might have shared some characteristics of blocked practice. Recent neuroimaging studies have provided substantial evidence that many cortical regions (corticomotor system) are less active when participants are submitted to a repetitive, constant (blocked) practice rather than a variable practice regimen (Cross, Schmitt, & Grafton, 2007; Lin, Fisher, Winstein, Wu, & Gordon, 2008; Lin et al., 2009; Lin, Winstein, Fisher, & Wu, 2010; Wymbs & Grafton, 2009).

Although the observation of a novice model provided observers with large trial-to-trial variability, presumably engaging observers in active information processing (Adams, 1986), it did not allow access to a strong standard of reference (i.e., expert performance) for comparison with the novice performance. Without this comparison, the trial-to-trial variability experienced when observing a novice performer provided the observer with less accurate and noisier information than mixed observation, limiting its efficacy.

Therefore, mixed model observation results in a better conceptualization of the targeted task compared to observing either a novice or expert model (Experiment 1). Mixed model observation presumably leads to more active information processing for (a) formation of a standard of reference (or template) and (b) error detection and correction mechanisms, which could result in the activation of more brain areas. This proposition is supported by the seminal work of Decety et al. (1997), who showed that observing with the intent to imitate, which arguably occurs when observing an expert model, was associated with the activation of brain regions involved in the planning and generation of actions. This group also showed that observing with the intent to recognize, which we speculate may have occurred when observing a novice model, activated memory-encoding structures.

In addition, the brain regions associated with error processing have been shown to be activated when participants observe movement error (Bates, Patel, & Liddle, 2005; Miltner, Brauer, Hecht, Trippe, & Coles, 2004; Shane, Stevens, Harenski, & Kiehl, 2008; van Schie, Mars, Coles, & Bekkering, 2004). For instance, van Schie et al. (2004) showed more cortical activation in error trials than correct trials for participants who performed the experimental task (execution condition) and observed a model perform the same task (observation condition). Taken together, this result supports our hypothesis that the CNS is more active during mixed model observation than expert or novice model observation, resulting in better task learning.

An alternative explanation for our findings could be that any combination of two models, regardless of their skill level, is better than the observation of a single model. For example, observing many novice models might enable one to detect a larger spectrum of possible errors and corrections for these errors, potentially improving learning. Similarly, observing many experts might enable one to detect similarities in performances and use these common features as an abstract template for how to perform, ignoring minor individual differences in the models' performance. This could certainly be the case when learning a complex motor task, such as a golf swing, and is thus worth future exploration.

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Figure captions

Figure 1. View of the apparatus and the task used in the study. Participants had to leave the starting base and hit the first, second and third barriers in a clockwise motion before finally reaching the target.

Figure 2. Absolute constant error (|CE|) in total movement time and root mean square error (RMSE) of intermediate times as a function of the number of trials for the expert and novice models used in Experiment 1.

Figure 3. Absolute constant error (|CE|) and variable error (VE) in total movement time and root mean square error (RMSE) of intermediate times as a function of experimental phases for the physical practice (PP), observation-novice (N), observation-expert (E), observation-mixed (M), and control groups in Experiment 1.

Figure 4. Absolute constant error (|CE|) and variable error (VE) in total movement time and root mean square error (RMSE) as a function of the blocks of trials for the physical practice group (PP), observation-novice (N), observation-expert (E), and observation-mixed groups in ACQ2 of Experiment 1.

Figure 5. Absolute constant error (|CE|) in total movement time and root mean square error (RMSE) of intermediate times for the sequence of trials shown to the observers for the expert (E) model and the different novice models in the three mixed-observation groups (M→, Mσ, and M↑) in Experiment 2.

Figure 6. Absolute constant error (|CE|) and variable error (VE) in total movement time and root mean square error (RMSE) of intermediate times as a function of experimental phases for the physical practice group (PP), the three observation-mixed groups (M→, Mσ, and M↑), and the control group in Experiment 2.

Table 1: Groups and experimental phases in Experiment 1

Phase / Group	Pre-test	Acquisition 1 (ACQ1)	Immediate Retention/Transfer (Imm. RET/TR)	Acquisition 2 (ACQ2)	10 minutes Retention/Transfer (RET/TR10)	24 hour Retention/Transfer (RET/TR24)
Physical Practice (PP)	Perform 20 physical practice trials with no KR	Perform 60 physical practice trials + KR	Perform 40 (20/20) physical practice trials with no KR	Perform 60 physical practice trials + KR	Perform 40 (20/20) physical practice trials with no KR	Perform 40 (20/20) physical practice trials with no KR
Observation -Novice (N)	Perform 20 physical practice trials with no KR	Observe a novice model + KR (60 trials)	Perform 40 (20/20) physical practice trials with no KR	Perform 60 physical practice trials + KR	Perform 40 (20/20) physical practice trials with no KR	Perform 40 (20/20) physical practice trials with no KR
Observation -Expert (E)	Perform 20 physical practice trials with no KR	Observe an expert model + KR (60 trials)	Perform 40 (20/20) physical practice trials with no KR	Perform 60 physical practice trials + KR	Perform 40 (20/20) physical practice trials with no KR	Perform 40 (20/20) physical practice trials with no KR
Observation -Mixed (M)	Perform 20 physical practice trials with no KR	Observe a mixed model + KR (60 trials)	Perform 40 (20/20) physical practice trials with no KR	Perform 60 physical practice trials + KR	Perform 40 (20/20) physical practice trials with no KR	Perform 40 (20/20) physical practice trials with no KR
Control	Perform 20 physical practice trials with no KR	Do not practice	Perform 40 (20/20) physical practice trials with no KR	Do not practice	Perform 40 (20/20) physical practice trials with no KR	Perform 40 (20/20) physical practice trials with no KR

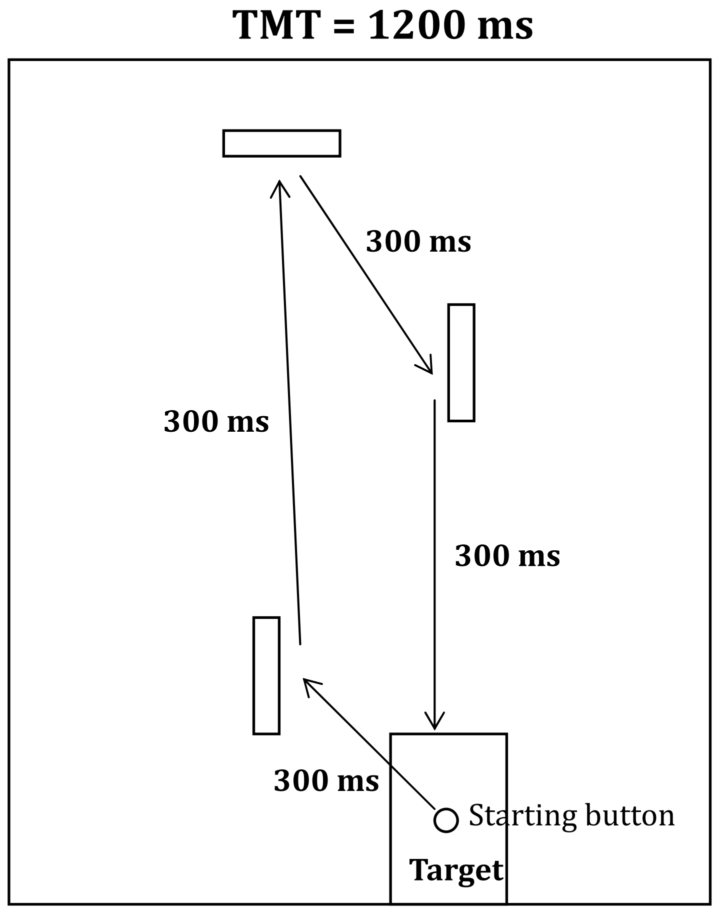


Figure 1

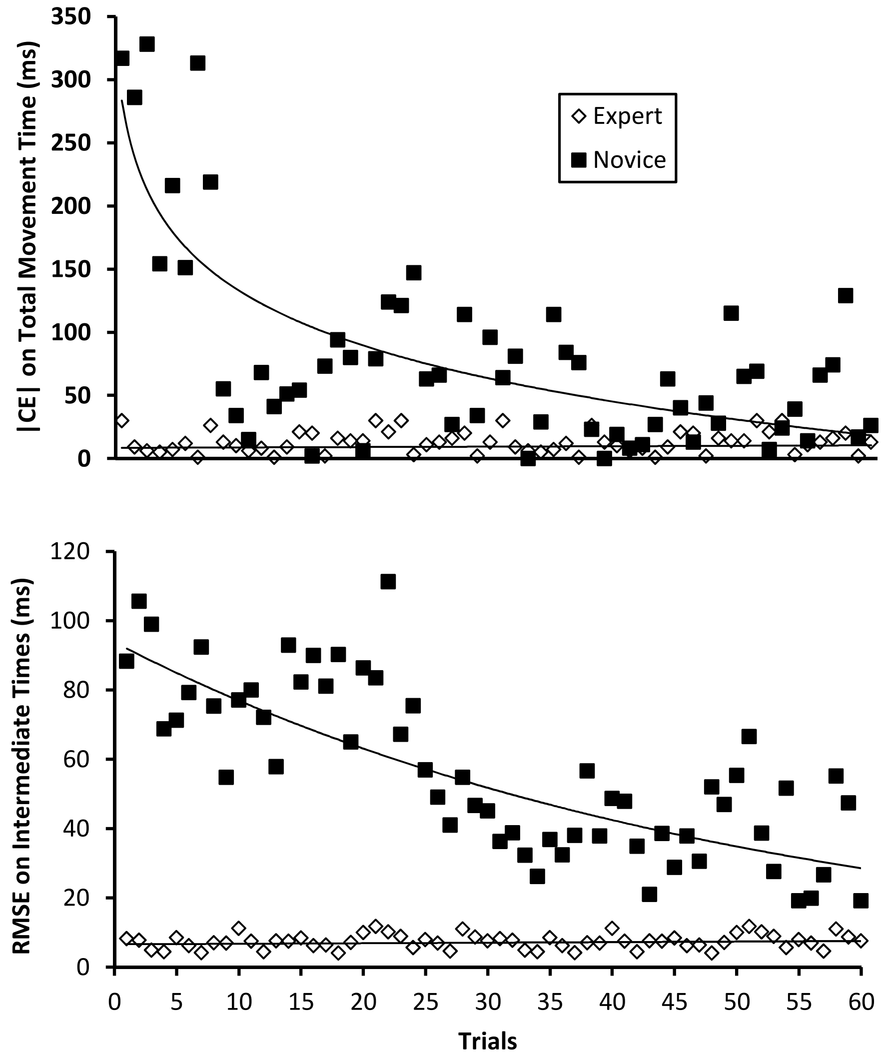

350
300
250
200
150
100
50
0
|CE| on Total Movement Time (ms)
Expert
Novice
120
100
80
60
40
20
0
RMSE on Intermediate Times (ms)
0
5
10
15
20
25
30
35
40
45
50
55
60
Trials

Figure 2

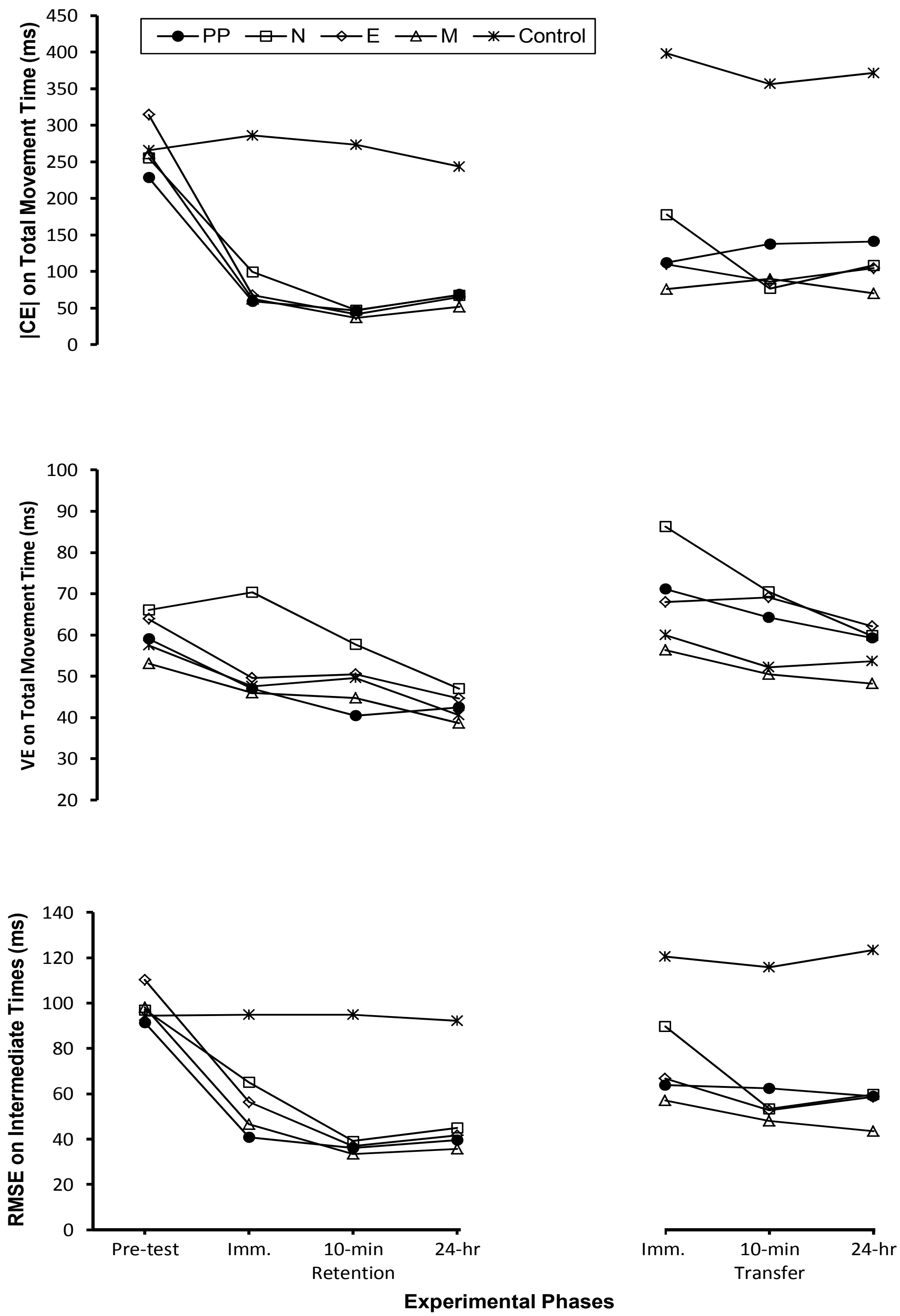

PP
N
E
M
Control
|CE| on Total Movement Time (ms)
VE on Total Movement Time (ms)
RMSE on Intermediate Times (ms)
Pre-test
Imm.
10-min
24-hr
Retention
Imm.
10-min
24-hr
Transfer
Experimental Phases

Figure 3

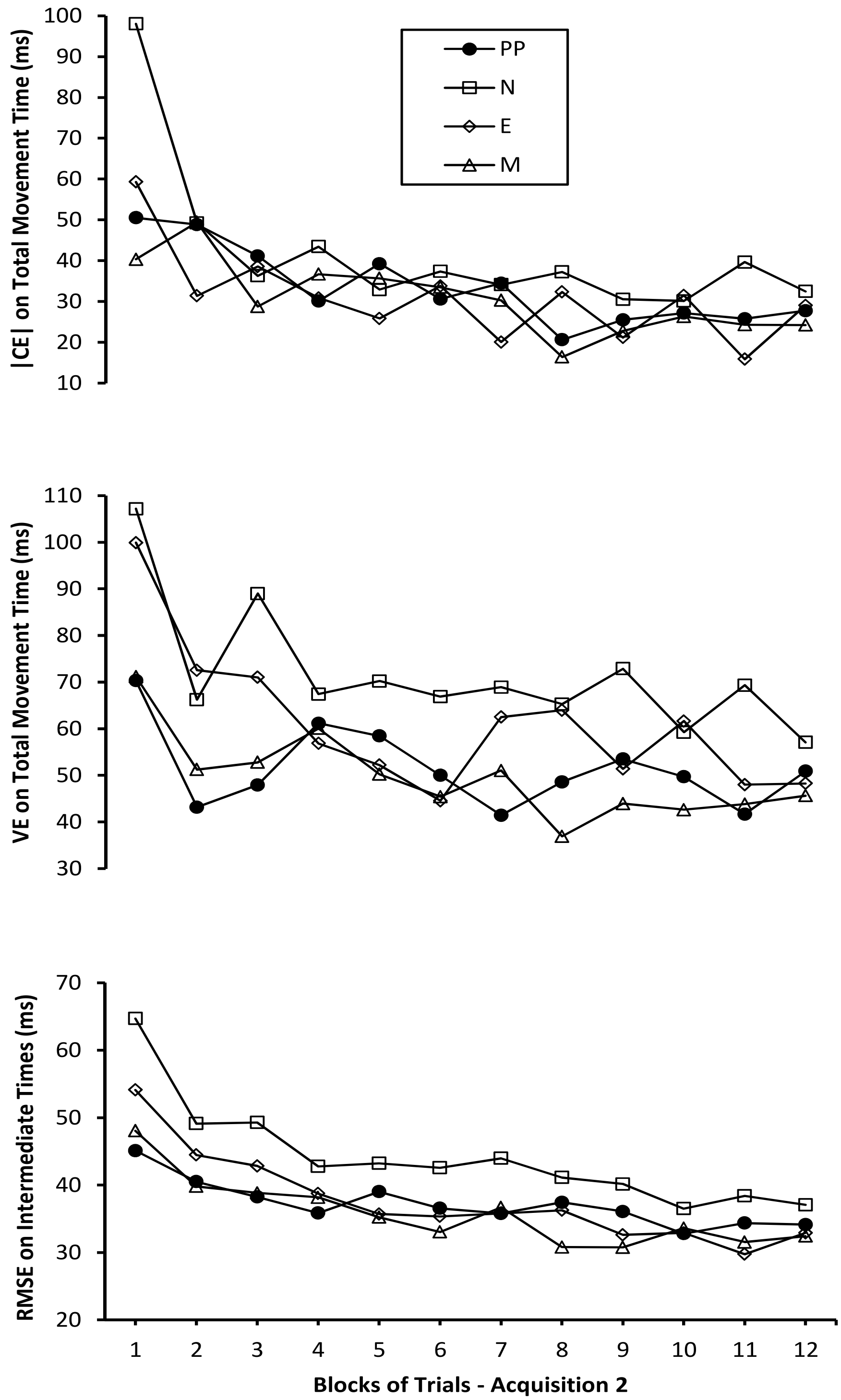

PP
N
E
M
|CE| on Total Movement Time (ms)
VE on Total Movement Time (ms)
RMSE on Intermediate Times (ms)
Blocks of Trials - Acquisition 2

Figure 4

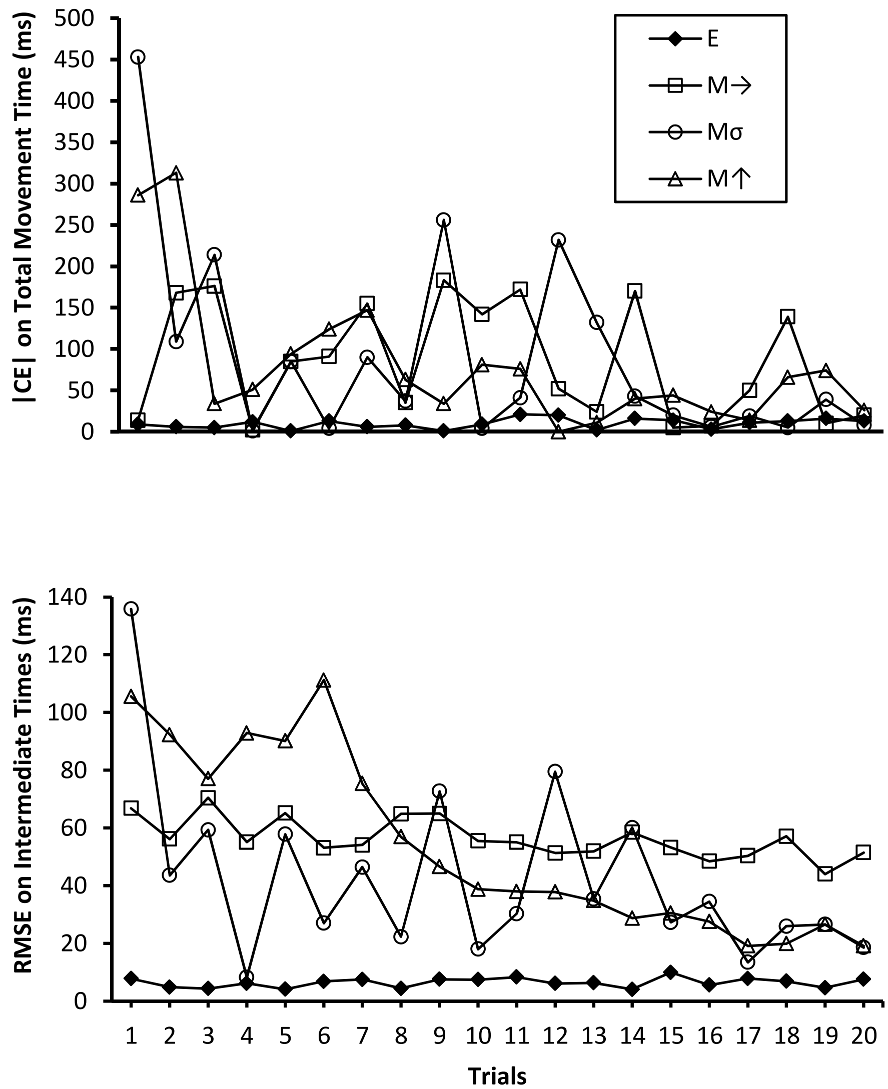
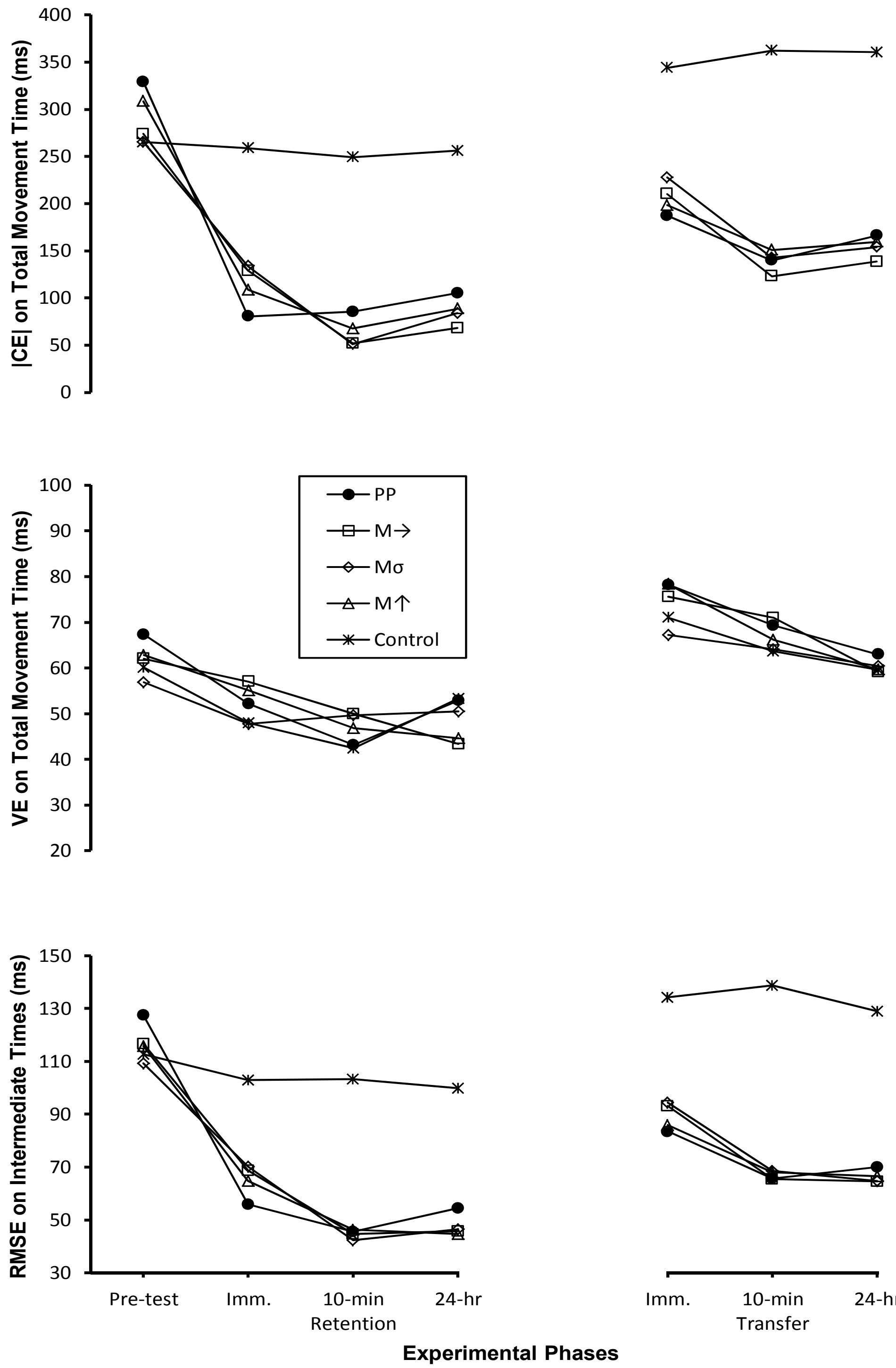

E
M→
Mσ
M↑
|CE| on Total Movement Time (ms)
0
50
100
150
200
250
300
350
400
450
500
RMSE on Intermediate Times (ms)
0
20
40
60
80
100
120
140
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Trials

Figure 5



|CE| on Total Movement Time (ms)
VE on Total Movement Time (ms)
RMSE on Intermediate Times (ms)
PP
M→
Mσ
M↑
Control
Pre-test
Imm.
10-min
24-hr
Retention
Imm.
10-min
24-hr
Transfer
Experimental Phases

Figure 6

Chapter 3 : Study 2

Effects of the model's handedness and visual viewpoint on observational learning

Hassan Rohbanfard and Luc Proteau

Département de kinésiologie, Université de Montréal

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Abstract

Observation promotes motor skill learning. However, little is known about the type of model and conditions of observation that can optimize learning. In this study, we investigated the effects of the model's handedness and the observer's viewpoint on the learning of a complex spatiotemporal task. Four groups of right-handed participants observed, from either a first- or third-person viewpoint, right- or left-handed models performing the task. Observation resulted in significant learning. More importantly, observation of same-handed models resulted in improved learning as compared with observation of opposite-handed models, regardless of the observer's viewpoint. This suggests that the action observation network (AON) is more sensitive to the model's handedness than to the observer's viewpoint. Our results are consistent with recent studies that suggest that the AON is linked to or involves sensorimotor regions of the brain that simulate motor programming as if the observed movement was performed with one's own dominant hand.

Keywords: Allocentric observation, egocentric observation, relative timing, observation perspective, model handedness, action observation network, motor skill learning

Effects of the model's handedness and visual viewpoint on observational learning

Observation facilitates learning of a motor skill by permitting the observer to determine the key spatial and/or temporal features of the task, which spares him or her the need to create a cognitive representation of the action pattern through trial and error (Blandin, Proteau, & Alain, 1994; Carroll & Bandura, 1982; Newell, 1981; Pollock & Lee, 1992; Schmidt & Lee, 2005; Scully & Newell, 1985; for reviews on observational learning, see McCullagh & Weiss, 2001; Wulf & Mornell, 2008; Wulf, Shea, & Lewthwaite, 2010). These findings are supported by recent brain imaging studies, which indicated that an "action observation network" (AON; including premotor cortex, inferior parietal lobule, superior temporal sulcus, and supplementary motor area) engages the observer in processes similar to those that occur during physical practice (Brown, Wilson, & Gribble, 2009; Buccino et al., 2001; Cisek & Kalaska, 2004; Cross, Kraemer, Hamilton, Kelley, & Grafton, 2009; Dushanova & Donoghue, 2010; Fogassi et al., 2005; Frey & Gerry, 2006; Gallese, Fogassi, Fadiga, & Rizzolatti, 2002; Grafton, Fadiga, Arbib, & Rizzolatti, 1997; Shmuelof & Zohary, 2006).

However, little is known about the attributes of a good model. In real-life situations, one may observe a model performing a task with the opposite hand (hereafter called an opposite-handed model), such as when a left-handed trainer shows a right-handed pupil how to putt or drive a golf ball. Moreover, the model may be observed from different viewpoints. The pupil may face the trainer (third-person observation) or be located such that he or she has the same perspective as the trainer (first-person observation). From a third-person perspective, when a left-handed trainer faces a right-handed pupil, they both swing the club in the same direction, as if the pupil was facing a mirror. A right-handed trainer (hereafter called a same-handed model) facing a right-handed pupil will swing the club in the opposite direction. However, when a same-handed trainer is observed from a first-person perspective, the pupil observes the trainer swinging the club in the same direction as the pupil. Does the pupil learn more when observing an opposite-handed trainer, or is the skill learned more easily when the pupil observes a same-handed trainer who is either (a) facing him or her (i.e., third-person observation) or (b) placed in the same perspective (i.e., first-person observation)?[4]

Brain imaging studies have revealed that observing a left or right hand reach-and-grasp movement from a first-person perspective (also called egocentric) resulted in larger blood oxygenation level-dependent (BOLD) responses in the contralateral anterior intraparietal cortex of right-handed observers, which is similar to when one performs the observed task (Shmuelof & Zohary, 2006, 2008). However, when the observation was from a third-person perspective (i.e., the model faces the observer, also called allocentric),

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[4] It should be noted that our study differs from previous work addressing the question of whether observational learning is effector dependent or independent (Boutin, Fries, Panzer, Blandin & Shea, 2010; Gruetzmacher, Panzer, Blandin, & Shea, 2011, Osman, Bird, & Heyes, 2005). In the pres*en*t study, we want to determine whether a right-handed observer performing the task with his or her right hand (which is usually the case in most real-life situations, such as learning how to bowl, play golf, and tennis) can learn better from a right-handed or left-handed model depending on the observer's perspective and not whether this learning can be transferred so that the observers can perform the task with both right and left hands.

BOLD data revealed a larger activation of the ipsilateral anterior superior parietal lobule (aSPL; Shmuelof & Zohary, 2008). Observing a right-handed action increased BOLD activity in the right hemisphere. In this vein, using transcranial magnetic stimulation (TMS), Alaerts et al. (2009) had participants watch videos showing left and right hand extension movements from a first- or third-person perspective. Electromyography data demonstrated an increase in the left primary motor cortex excitability when participants observed the right hand from a first-person perspective or when participants observed the left hand from a third-person perspective (see also Hesse, Sparing, & Fink, 2009). Therefore, learning a motor skill might be facilitated when observing a same-handed trainer from a first-person perspective or an opposite-handed trainer from a third-person perspective. However, the observation of increased activation of different brain regions does not necessarily mean that behaviorally significant differences in the learning of a complex motor task will accompany these activation changes. Therefore, our goals were to determine whether same-handed or opposite-handed models would better promote learning and whether this effect would be mediated by the observer's perspective.

Method

Participants

Seventy-two self-declared right-handed students (46 females) from the Département de kinésiologie at the Université de Montréal participated in this experiment. All participants reported normal or corrected-to-normal vision, had no prior experience with the experimental task, were unaware of the goals of the study, and signed an informed consent form. The participants were each paid $20 CDN for their participation. Two additional participants served as right- and left-handed novice models. One author (H. R.) served as the expert model with both right and left hands. The Health Sciences Ethics Committee of the Université de Montréal approved this study.

Apparatus and task

Two apparatuses were used in this study. The first apparatus (hereafter called the right apparatus) is illustrated in Figure 1 (top left panel). This apparatus consisted of a wooden base with three barriers (height: 11 cm, width: 8 cm) and a start button embedded in a final target (11 X 8 cm). The barriers were placed perpendicular to the wooden base at the beginning of each trial, closing a micro switch circuit. The micro switches were connected to a computer via the I/O port of an A-D converter (National Instruments), and a millisecond timer was used to record the total movement time (TMT) and the time required to complete each segment of the task (intermediate times; ITs). The frontal (a negative value indicates that the barrier is located to the left of the starting base) and the sagittal Cartesian coordinates of the first, second and third barriers relative to the start button were -12.5 and 9 cm, -13.5 and 41.5 cm, and 0 and 29 cm, respectively. While sitting in front of the apparatus, a participant's task was to initiate his or her movement from the starting position, trip the first, second, and third barriers successively, and then end their movement on the target. The participants were asked to perform each segment of the task in an IT of 300 ms, leading to a TMT of 1200 ms. The second apparatus (hereafter called the left apparatus; see Figure 1, top right panel) was the mirror image of the first one.

In a pilot study, we determined the natural relative timing used by individuals who physically practiced the experimental task (Collier & Wright, 1995) with their right, dominant hand. Specifically, 3 participants who did not take part in the present study were asked to complete the task in a movement time of 1200 ms for 60 trials. Although we recorded both TMTs and ITs, the participants received feedback only on the TMT following each trial. Twenty practice trials allowed the participants to approach the goal TMT of 1200 ms. Data from the remaining forty trials revealed stable relative timing both within and across participants. On average, the participants used a relative timing of 17.2%, 29.0%, 23.2% and 30.6% to complete the first, second, third and fourth segments of the experimental task, respectively (within- and between-participant variability fluctuated between 1.0% and 2.4%; see also Blandin et al., 1999 for a similar observation). Therefore, the task required that participants modify the naturally emergent relative timing pattern for this task.

Experimental groups and procedure

The participants were randomly assigned to one of the six following groups: one control group, one physical practice group (PP), and four observation groups (left-handed model/first-person [L-1st]; left-handed model/third-person [L-3rd]; right-handed model/first-person [R-1st]; right-handed model/third-person [R-3rd]; for details see below and Table 1). After having been informed of the movement sequence to be performed, the participants completed the following four experimental phases: pre-test (PRT), acquisition (ACQ), and 10 min and 24 hr retention tests (RET10 and RET24). The movement pattern, ITs and

TMT, were illustrated on a poster located directly in front of the apparatus during all experimental phases.

In the PRT, a participant used his or her right hand to perform 10 trials using the right apparatus. No knowledge of the results (KR) was provided during this phase.

During ACQ, a participant in the physical practice group physically practiced the task with his or her right hand on the right apparatus for 40 trials. After each trial, the participant received the KR in milliseconds on both the TMT and ITs. The KR was presented on a computer screen and remained visible for 7 seconds (see bottom of Figure 1). The participants in all observation groups watched a film of a model performing the experimental task for 40 trials. The video was presented on a 37-inch monitor (Sony Bravia KDL-37M3000) located directly in front of the participant. Following each trial, the KR concerning the performance of the model on both the TMT and ITs was presented on the monitor for 7 seconds. The observation groups differed by the type of model the participants watched (right-handed or left-handed model) and whether the film was presented using a first- or third-person perspective. The right-handed models were shown using the right apparatus, whereas the left-handed models were shown using the left apparatus. For all groups, the videos were closed captioned so that the observers could clearly see the apparatus and the model's motion throughout the duration of a trial. The performance of the expert model was nearly perfect and was similar for both the right and left hands. On average (SD), when using his right hand, the expert spent 301 (6.6), 303 (7.2), 300 (6.7), and 299 (5.8) ms on the first, second, third, and fourth segment of the task, respectively (TMT = 1202, SD = 10.1). When using his left hand, the expert spent 304

(7.5), 301 (5.9), 303 (7.1), and 298 (5.5) ms on segments 1 to 4, respectively (TMT = 1205, SD = 11.7). The right- and left-handed novice models showed gradual and similar improvements during each practice (see Figure 2). We opted to use a mixed schedule of observation. Specifically, the participants watched a film showing 20 trials performed by a novice model who gradually improved his performance through practice and 20 trials performed by an expert model. Thus, observation provided a template of what needed to be done (expert model) and on how to correct one's movement to be successful (novice observation). The model was alternated every 5 trials (e.g., novice: trials 1-5 and expert: trials 6-10). The participants were informed that they would observe both an expert and a novice model. Prior to each set of 5 trials, they were also reminded that they would observe the expert or novice model. All participants in the observation groups were informed at the beginning of the acquisition phase that they would have to perform the task using their right hand and the same apparatus as in the pre-test. The participants in the control group did not practice during this phase. Instead, they read a newspaper or magazine provided to them for the same duration as the observation or physical practice for the other groups (approximately 10 minutes).

Ten minutes and 24 hours after the end of the acquisition phase, all participants performed retention tests similar to the pre-test described above.[5] No KR was provided during these phases.

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[5] It could be argued that because participants in the L-1st and L-3rd groups observed a left-handed model but performed the task using their right hand, a more appropriate label for these tests would be "transfer" rather than "retention". However, because a transfer test evaluates the performance of the participants at a task that was different from what they specifically wanted to learn, we opted to use the "retention" label.

Data analysis

To determine the accuracy and consistency of the participants' movements, we computed the absolute constant error (|CE|) and variable error (VE) of the total movement time, respectively. We opted to use |CE| instead of CE because, within all groups, approximately half of the participants undershot the target TMT, whereas the other half overshot it. For ITs, we computed a root mean square error (RMSE), which presents in a single score how much each participant deviated from the prescribed relative timing pattern.

$RMSE = \sqrt{\sum_{Segment\ 1}^{Segment\ 4}\left(\frac{(ITi-300)^2}{4}\right)}$, where ITi is the intermediate time of segment i for each trial.

The data of the three dependent variables were individually submitted to two analyses. In the first analysis, we determined whether the observation led to significant learning of the TMT and ITs of the task. The data were submitted to an ANOVA contrasting 6 groups (physical practice, control, observers R-1st, observers R-3rd, observers L-1st, and observers L-3rd) x 3 experimental phases (pre-test, retention 10 min, retention 24 hr) x 2 blocks (trials 1-5, 6-10) using repeated measurements on the last two factors. Next, to determine whether some observation conditions resulted in better learning of the task, the data from the observation groups were submitted to an ANOVA contrasting the 2 handedness of the models (right vs. left) x 2 perspectives of observation (first- vs. third-person) x 2 experimental phases (retention 10 min, retention 24 hr) x 2 blocks (trials 1-5, 6-10) using repeated measurements on the last two factors.

Before computing the different ANOVAs, three specific assumptions of the ANOVA were tested. The z scores of the skewness and kurtosis values were calculated to test the normality of the distribution (Tabachnick & Fidell, 2007). To verify the homogeneity of the variances, Hartley's F_{max} test was used. Finally, the degrees of freedom were adjusted as suggested by Greenhouse and Geisser (1959) when Mauchly's test of sphericity was significant. However, the original degrees of freedom were presented when the effects were found to be significant following the Greenhouse-Geisser correction. All significant effects are reported at $p < 0.05$ and were corrected for the number of comparisons (Bonferroni adjustment; Cardinal & Aitken, 2006).

Results

Total movement time

|CE|. The results of the first analysis revealed significant main effects of group, $\underline{F}$ (5, 66) = 3.64, and phase, $\underline{F}$ (2, 132) = 31.97, and a significant group x phase interaction, $\underline{F}$ (10, 132) = 2.29. As illustrated in Figure 3 (upper panel), the breakdown of the interaction revealed no significant difference between groups in PRT, $\underline{F} < 1$; however, in both the 10 min, $\underline{F}$ (5, 66) = 8.54, and the 24 hr retention tests, $\underline{F}$ (5, 66) = 10.10, the control group had a significantly larger |CE| than the five remaining groups, which did not differ significantly from one another. Figure 3 also illustrates that all experimental groups, but not the control group, exhibited a significantly reduced |CE| when comparing the PRT to the other two experimental phases. In addition, when comparing the 10 min to the 24 hr retention test, we found a significant increase in |CE| for the physical practice group ($p = 0.019$) but not for the four observation groups ($p > 0.90$ for all groups).

The results of the second analysis revealed no significant main effect or interaction. Thus, the four observation groups exhibited significant improvements in the accuracy of TMT, with no differences related to the conditions of observation.

VE. The results of the first analysis revealed significant main effects of phase, F (2, 132) = 41.48, and block, F (1, 66) = 5.06, and a significant phase x block interaction, F (2, 132) = 3.31. The breakdown of the interaction revealed a significantly larger VE in block 1 than in block 2 in the PRT (71 ms and 61 ms, respectively), whereas no significant between-block difference was found in both the 10 min (50 ms and 50 ms for blocks 1 and 2, respectively) and the 24 hr retention phases (42 ms and 40 ms for blocks 1 and 2, respectively). Post hoc comparisons of the phase main effect revealed that VE significantly decreased from one experimental phase to the next ($p < 0.01$ for all phases).

The results of the second analysis revealed a significant main effect of phase, F (1, 44) = 12.21, and a significant phase x view interaction, F (1, 44) = 5.81. The breakdown of the interaction revealed a decrease in VE from the 10 min to the 24 hr retention test when observing from the first-person perspective (49 ms and 36 ms, respectively) but not when observing from the third-person perspective (45 ms and 42 ms, respectively).

Intermediate times

The results of the first ANOVA computed on the RMSE revealed significant main effects of phase, F (2, 132) = 70.91, and group, F (1, 66) = 10.32, and significant phase x group, F (10, 132) = 4.26, and phase x block interactions, F (2, 132) = 4.61. The breakdown of the phase x group interaction revealed the following. As illustrated in Figure 3 (bottom panel), there were no significant between-group differences in the PRT, $F < 1$. In both the 10 min and 24 hr retention tests, the control group had a significantly larger RMSE than did the remaining five groups, which did not differ significantly from one another; F (5, 66) = 19.24 and 24.14, for the 10 min and 24 hr tests, respectively. Figure 3 also illustrates that all experimental groups, but not the control group, exhibited significantly reduced RMSEs when comparing the PRT to the two retention tests. However, when comparing the 10 min to the 24 hr retention test, we found a significant increase in the RMSE for the physical practice group ($p = 0.005$) but not for the observation groups ($p > 0.14$ for all groups). The breakdown of the phase x block interaction revealed that the participants had a significantly larger RMSE in block 1 than in block 2 of the PRT (123 ms and 117 ms, respectively), whereas no significant difference between blocks 1 and 2 was found in either the 10 min (81 ms and 82 ms, respectively) or the 24 hr retention test (77 ms and 78 ms, respectively).

The results of the second analysis revealed significant main effects of phase, F (1, 44) = 9.26, and handedness, F (1, 44) = 13.10. Post hoc comparisons revealed that the participants showed decreased RMSEs when comparing the 10 min (77 ms) to the 24 hr retention test (68 ms). More importantly, the participants had a significantly smaller RMSE when observing a right-handed model (63 ms) than they did when observing a left-handed model (82 ms; Figure 4).

Thus, all forms of observation used in the present study led to significant learning of intermediate times. However, participants learned more when observing a same-handed model than they did when observing an opposite-handed model.

Discussion

Observation results in learning of a motor skill (Blandin, Lhuisset, & Proteau, 1999; Hayes, Elliott, & Bennett, 2010; McCullagh & Weiss, 2001; Shea, Wright, Wulf, & Whitacre, 2000; Wulf & Mornell, 2008; Wulf et al., 2010). However, little is known concerning the type of model and conditions of observation that can optimize motor skill learning. In the present study, our goals were to determine whether a same-handed or an opposite-handed model would better promote learning of a complex spatiotemporal task and whether this effect would be mediated by the observer's perspective.

The results of the present study are straightforward. Regardless of the models' handedness or the observers' perspective, results from the two retention tests revealed that all observation groups learned to complete their movements in the prescribed TMT at least as accurately as did the physical practice group and significantly better than the control group. These results were consistent with previous findings indicating that the TMT can be learned through observation (Blandin et al., 1999; Rohbanfard & Proteau, 2011; Trempe, Sabourin, Rohbanfard, & Proteau, 2011). In addition, our results indicated that the observation permitted the participants to learn the TMT and ITs concomitantly (We return to this point below). Importantly, the physical practice group, unlike the observation groups, did not perform as well in the 24 hr retention test as they did in the 10 min retention test. This is consistent with our previous study (Rohbanfard & Proteau, 2011) and suggests that a 10 min retention test might reflect short-term performance effects more than learning effects (see Schmidt and Lee, 2005) following the physical practice.

In addition, the results revealed that, for both same-handed and opposite-handed models, different observation perspectives (first- vs. third-person) resulted in no significant differences in the learning of the task (Figure 4). This was consistent with the results of previous behavioral studies investigating the effects of the observation viewpoint in imitation (Ishikura & Inomata, 1995; Sambrook, 1998). For example, Ishikura and Inomata had participants observe a model performing a sequential movement task from a first-person or a third-person perspective. Their results showed that the first-person group significantly outperformed the third-person group on immediate recall tests. However, both groups performed equally well in a series of delayed retention tests completed 1 day, 1 week, or 5 months later. Ishikura's and Inomata's results suggest that although the first-person perspective resulted in better performance than did the third-person perspective, it resulted in similar long-term retention and, thus, learning of the task.

More notably, our results revealed that the observation of a same-handed model led to significantly better learning of the ITs than did observation of an opposite-handed model from both first- and third-person perspectives. For the first-person perspective, our results were consistent with behavioral studies (Blandin et al., 1999; Boutin et al., 2010; Gruetzmacher et al., 2011; Heyes & Foster, 2002; Osman et al., 2005) and brain imaging studies, which demonstrated that observation results in contralateral activation of brain regions that were solicited during physical practice (Aziz-Zadeh, Koski, Zaidel, Mazziotta, & Iacoboni, 2006; Aziz-Zadeh, Maeda, Zaidel, Mazziotta, & Iacoboni, 2002; Maeda, Kleiner-Fisman, & Pascual-Leone, 2002; Pilgramm et al., 2010; Shmuelof & Zohary, 2006, 2008). This may explains why right-handed participants were more accurate when they observed a same-handed model than when they observed an opposite-handed model from a first-person perspective. Furthermore, our results supported Michel and Harkins's study (1985), in which right- and left-handed participants observed a knot-tying task performed by a right-handed or left-handed model from a first-person perspective. Their results showed that the participants learned significantly faster from a same-handed model than from an opposite-handed model. Together, these results suggest that the observation of an opposite-handed model requires some additional processing of information (e.g., transformation of visual information), which could limit or slow the learning of a new motor skill.

When observing from a third-person perspective, our results were inconsistent with the pattern of activation revealed in TMS (Alaerts et al., 2009; Hesse et al., 2009) and brain imaging studies (Hesse et al., 2009; Kilner, Marchant, & Frith, 2009; Shmuelof & Zohary, 2008). Specifically, recent studies have indicated a larger activation of the ipsilateral aSPL (Shmuelof & Zohary, 2008) and a larger excitability of the ipsilateral primary motor cortex (Alaerts et al., 2009; Hesse et al., 2009) for movements observed from a third-person perspective. In addition, several studies have reported that young participants had a tendency to imitate the actions of others in a mirror-imaged manner when observed from a third-person perspective (Avikainen, Kulomaki, & Hari, 1999; Chiavarino, Apperly, & Humphreys, 2007; Iacoboni et al., 2001). Together, these results suggest that the observation of a left-handed model from a third-person perspective should have facilitated learning in the observers. A possible cause for these divergent findings is that the participants in the above studies observed familiar gestures or imitated familiar upper/lower limb movements immediately after having observed them, with no specific spatial and/or temporal constraints. This is in stark contrast from learning a complex spatiotemporal pattern, as in the present study and most sport-like activities. It is possible that the intent of learning in conjunction with the stringent temporal constraints of our task might require the AON to transform the visual information depicted from a third-person perspective to fit with how the observer must perform the task. This transformation is likely easier to do or more natural when a right-handed individual observes a right-handed model.

This is consistent with the predictive coding framework of the simulation of observed actions advocated by Kilner and colleagues (Kilner et al., 2007a, b; Neal & Kilner, 2010). This model, like others (Miall, 2003; Wolpert et al., 2003), proposes that observers simulate an action they see using a generative or forward model of how they would perform the same action. However, in two recent papers, evidence was provided that the observer simulates the observed action as if performed by his or her dominant hand. Specifically, Neal and Kilner (2010) had right-handed participants observe video clips showing a right- or left-hand reach-and-grasp movement from either a first- or third-person perspective. In the “natural” condition, the videos were not altered in any significant way, whereas in the “manipulated” condition the videos were reflected about the vertical midpoint. Thus, in the latter condition, a right-hand movement filmed from a first-person perspective was shown as a left-handed movement from a third-person perspective, and so on. The participants were informed that half of the videos they were about to see had been altered using video software. Following each video presentation, they had to indicate whether the video had been manipulated. Although the participants reported that they were guessing, videos of natural right-hand movements that were viewed from a first-person or third-person perspective were reported as natural significantly more often than left-handed videos that had been manipulated to look as right-handed movements. No such difference was found between the natural and manipulated left-hand movements. This suggests that observers always simulate what they observed using a generative or forward model of how they would perform the same action using their dominant right-hand. This model is used to predict what should be observed. The differences between the simulated and the observed movements would be greater when observing a left- than a right-handed model, which would explain why participants considered left-hand movements as manipulated more often than right-hand movements. More recently, Press et al. (2011) used magnetoencephalography to record the cortical activity of right-handed participants performing sinusoidal up and down movements with their left or right arm or observing video clips of individuals performing the same movements from a third-person perspective. Their results revealed that the observation of right and left hand actions elicited changes in the left hemisphere sensorimotor activation across time (Broadman area 4), according to the phase of the observed movement. These changes would be expected if one was executing the observed movement, indicating that observation activated the motor program required for its execution with the observer's dominant right hand. Our results add to these previous findings by showing that the more accurate simulations hypothesized when a right-hand observer watched a right-hand movement also leads to a more accurate movement programming and execution, which would save practice time.

Finally, the benefit of observing a same-handed model for learning a complex motor skill might not apply to left-handed participants. Because left-handed people represent approximately 10% of the population (Ida & Mandal, 2003), they show a tendency to accommodate to the right-sided world (Coren & Halpern, 1991). This accommodation might result in left-handed people learning as quickly, and perhaps even more quickly, from right-handed rather than left-handed models. Future research is needed to address this issue.

An alternative interpretation of our findings could be that the observers coded the movement sequence in visual-spatial coordinates rather than in a motor coordinates. Because the apparatus used by the opposite-handed model was a mirror image of that used by the L-1st and L-3rd groups, it could explain why observation of a left-handed model did not favor learning as much as observation of right-handed model. Partial support for this interpretation comes from two recent studies (Boutin et al., 2010; Gruetzmacher et al., 2011). For example, in Boutin et al., right-handed participants observed a right-handed model moved a one-degree-of-freedom lever back-and-forth to reach a series of target locations as fast as possible. The sequence of target presentations was pre-determined and repeated 140 times. Following observation, the participants performed the same task as the models with their right arm. They also performed two transfer tests using their left arm. For these tests, the sequence of target presentation remained the same as during observation and, thus the visuo-spatial codes of what has been observed was maintained in transfer, whereas in the second test, the sequence of target presentation was the mirror image of what has been observed, which kept the motor coordinates (pattern of arm flexion and extension) unchanged between observation and test. The results revealed that the observers performed the task significantly faster when the visuo-spatial rather than the motor codes were maintained in transfer. This finding was replicated by Gruetzmacher et al. who used a relatively simple spatial-temporal movement sequence. Thus, it could be that an observer learns more from a same-handed than from an opposite-handed model because he or she codes the observed movement pattern in visuo-spatial coordinates and that these coordinates are maintained when observing a same-handed model. However, in both Boutin et al. and Gruetzmacher et al., the observers needed to learn the location of the targets, which could have made the visuo-spatial information more important than in the present study for which the target locations were known but the challenge was to learn a new imposed relative timing pattern. Future research should address this question.

Concomitant learning of TMT and IT

In the present study, we found that observation permitted the participants to learn the TMT and ITs concomitantly. This finding differs from previous observations from our laboratory (Blandin et al., 1999). Blandin et al. used a four-segment timing task similar to that used in the present study; these authors reported that observers first learned to complete their movements in the prescribed TMT and then learned the relative timing pattern. There are two procedural differences between Blandin et al. and the present study that could explain these divergent results. First, the imposed TMT was longer in the present study than in Blandin et al. (1200 ms vs. 900 ms). It could be that a more stringent TMT encouraged participants to learn to fit their movements within the appropriate time frame and then to proceed to make adjustments to relative timing. Second, we used a combination of expert and novice models (i.e., mixed model), whereas Blandin et al. used either an expert or a novice model. Thus, it could be that the observation of a mixed model, which has been shown to be more efficient for learning than the observation of either a novice or an expert model (Rohbanfard & Proteau, 2011), permitted the observers to learn TMT and IT concomitantly in the present study.

Conclusion

Observation, regardless of the model's handedness or the observer's perspective, promoted learning of a new motor skill. However, better learning of the temporal sequencing of the task occurred when the right-handed observer viewed a right-handed model from either a first- or a third-person perspective. Thus, the AON is more sensitive to the model's handedness than to the observer's viewpoint because the AON is linked to or involves sensorimotor regions of the brain that simulate motor programming. Our results were consistent with recent findings indicating that this putative simulation of the observed movements occurs in the left hemisphere of right-handed observers regardless of the model's handedness (Press et al., 2011). Our results also suggest that the observation for immediately reproducing the observed actions (i.e., imitation), as compared with observation for learning a new motor skill, might be based on different processes.

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Table 1: Groups and Experimental Phases

Groups \ Phase	Pre-test	Acquisition	10-min Retention	24-hr Retention
Physical practice	Perform 10 trials – No KR	Perform 40 physical practice trials + KR	Perform 10 trials – No KR	Perform 10 trials – No KR
Observers L-3rd		Observe left-handed model 3rd person 40 trials + KR		
Observers L-1st		Observe left-handed model 1st person 40 trials + KR		
Observers R-3rd		Observe right-handed model 3rd person 40 trials + KR		
Observers R-1st		Observe right-handed model 1st person 40 trials + KR		
Control		No practice		

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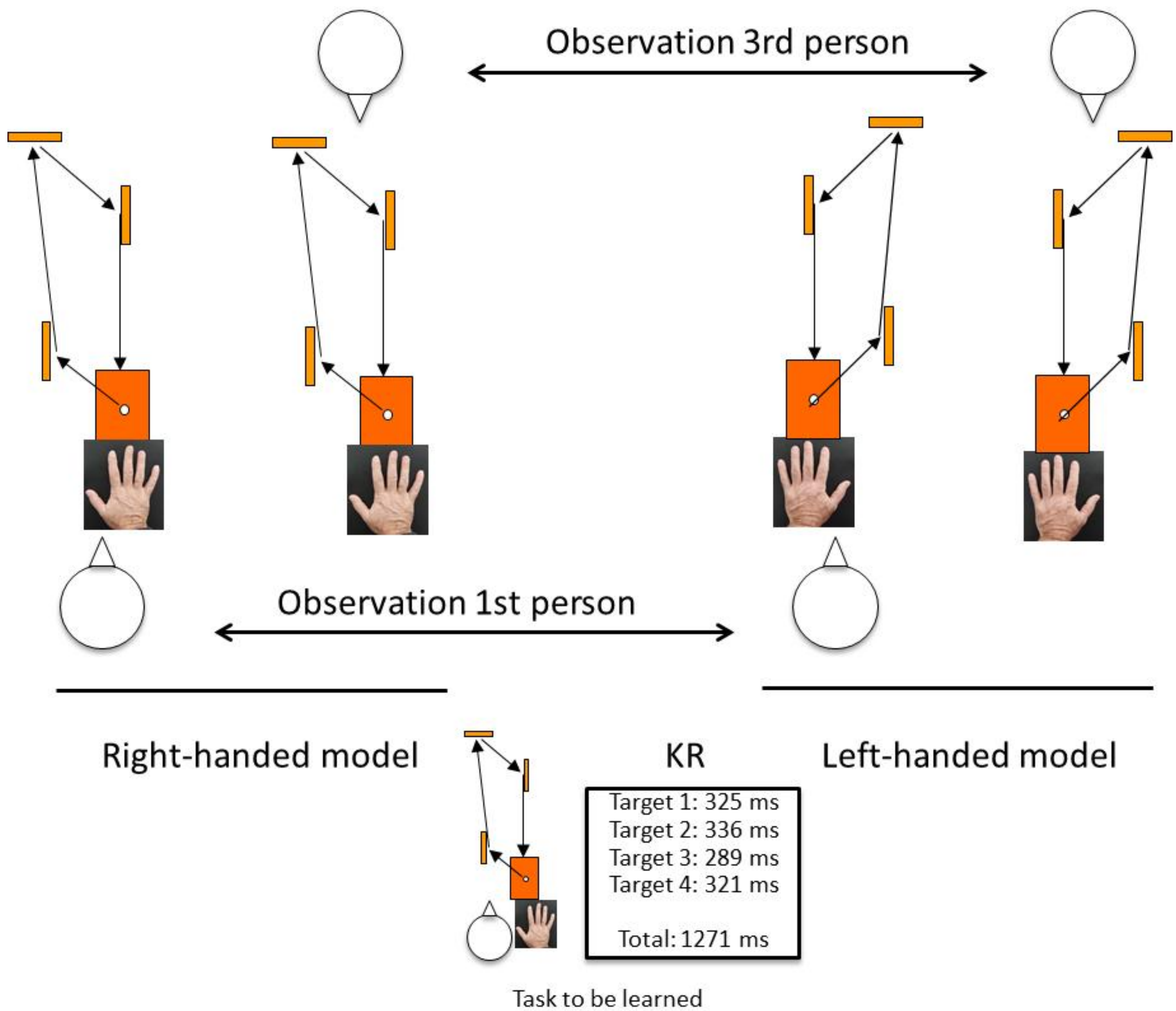
Figure captions

Figure 1. Top. View of the observer and of the model when using the left and right apparatuses. The participants' task was to initiate their movement from the starting position, trip the first, second, and third barriers successively, and then end their movement on the target in a counterclockwise (left) or a clockwise (right) motion. Bottom. In all groups, the participants knew that they would perform the task using their right hand and right apparatus. During the acquisition phase, the KR was provided on a computer screen illustrating the time spent on each segment of the task (IT) and the TMT.

Figure 2. Root mean square error on the intermediate times as a function of the number of trials for the right-handed (RH) and the left-handed (LH) novice models used in the present study.

Figure 3. Absolute constant error (upper panel) and variable error (middle panel) on the total movement time and root mean square error of the intermediate times (lower panel) as a function of experimental phases for the physical practice (PP), control, and four observation groups (L-3rd = Left-handed model/3rd person, L-1st = Left-handed model/1st person, R-3rd = Right-handed model/3rd person, R-1st = Right-handed model/1st person).

Figure 4. Effects of model's handedness (Left-handed [LH] vs. Right-handed [RH]) and observation viewpoint (3rd person vs. 1st person).



Observation 3rd person
Observation 1st person
Right-handed model
KR
Left-handed model
Target 1: 325 ms
Target 2: 336 ms
Target 3: 289 ms
Target 4: 321 ms
Total: 1271 ms
Task to be learned

Figure 1

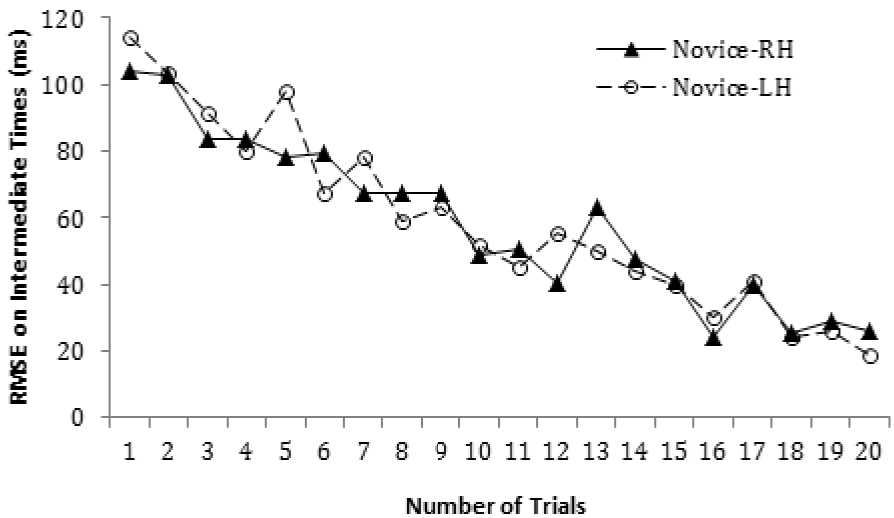

120
100
80
60
40
20
0
RMSE on Intermediate Times (ms)
Novice-RH
Novice-LH
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Number of Trials

Figure 2

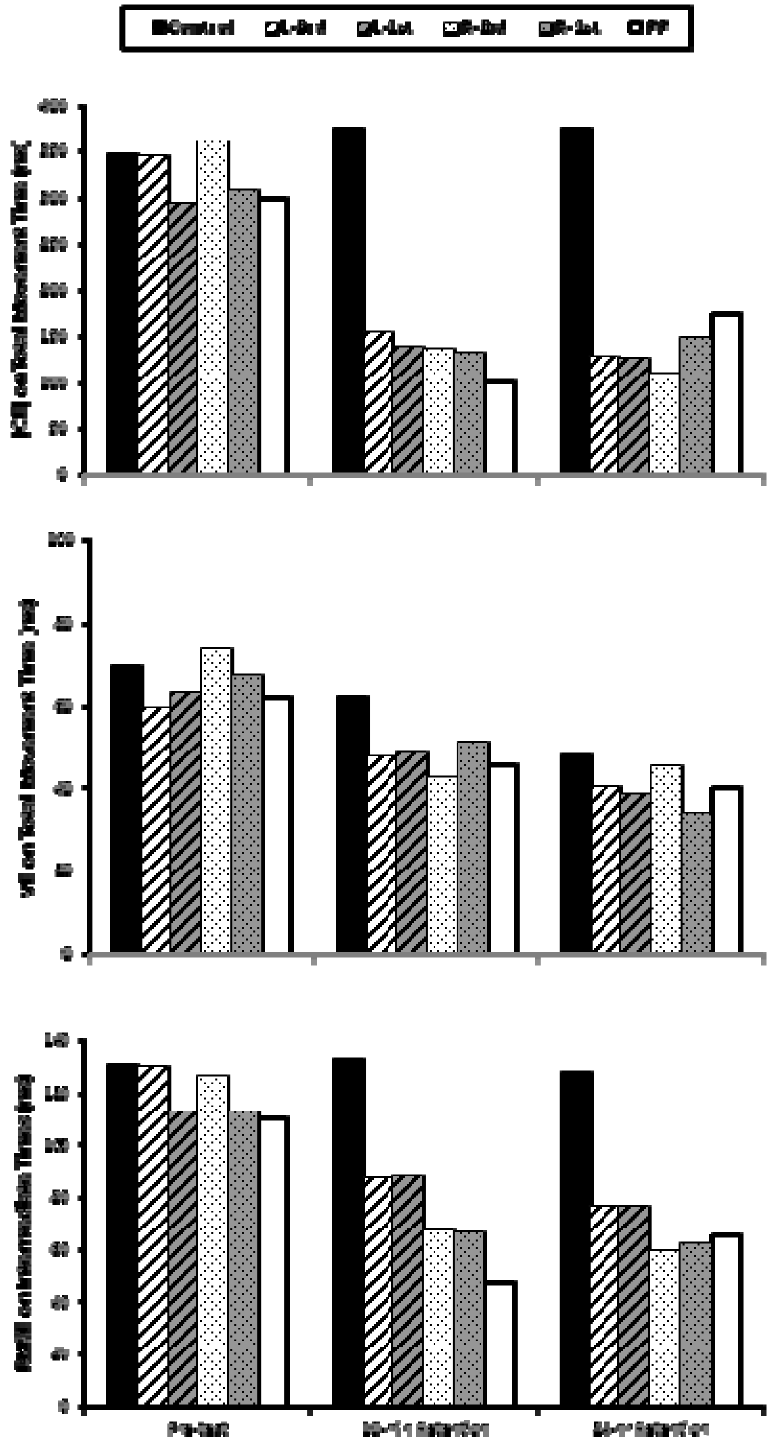


Figure 3

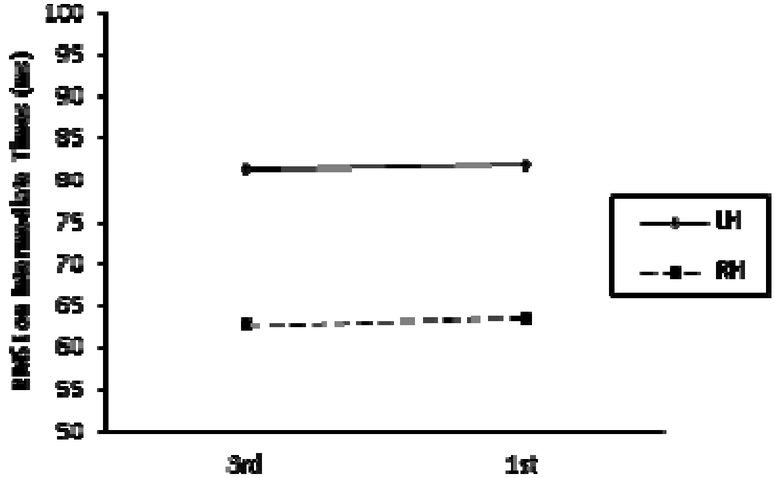


Figure 4

Chapter 4 : Study 3

Live vs. video presentation techniques in the observational learning of motor skills

Hassan Rohbanfard and Luc Proteau

Département de kinésiologie, Université de Montréal

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Abstract

The results of recent neuroimaging studies have revealed that activation of the action observation network (AON) is larger during live observation than video observation, as well as during observation from a first-person perspective compared to a third-person perspective. In the present study, we assessed whether this larger activation of the AON resulted in better learning of a motor skill. Six groups of participants (control, physical practice, live observation-1st person, live observation-3rd person, video observation-1st person, and video observation-3rd person) participated in a pre-test, an acquisition phase, and two delayed retention tests (10-min and 24-hour). The results of the two retention tests revealed that all groups of observers significantly outperformed the control group. However, observation did not differ significantly as a function of the media or the perspective of observation. These results indicate that numerous factors may influence the activation of the AON and that a larger activation of the AON is not synonymous with better learning of an observed task.

Keywords: Live observation, video observation, motor learning, action observation network, timing task

Live vs. video presentation techniques in the observational learning of motor skills

The observation of a live model performing a motor skill promotes learning in observers (Badets, Blandin, Wright, & Shea, 2006; Bird & Heyes, 2005, Experiment 1; Blandin, Proteau, & Alain, 1994; Buchanan & Dean, 2010; Buchanan & Wright, 2011; Heyes & Foster, 2002; Pollock & Lee, 1992). However, for practical purposes, the observation of a video presentation is often preferred to live observation to promote the learning of a new skill (Bird & Heyes, 2005, Experiments 2-3; Blandin, Lhuisset, & Proteau, 1999; Blandin & Proteau, 2000,experiment 1; Hayes, Elliott, & Bennett, 2010; Horn, Williams, & Scott, 2002; Osman, Bird, & Heyes, 2005; Rohbanfard & Proteau, 2011a, b; Trempe, Sabourin, Rohbanfard, & Proteau, 2011).

Although empirical evidence shows that one can learn a motor skill through both live observation and video observation, neuroimaging studies suggest that live and video observation are processed differently in the brain. For example, using positron emission tomography (PET), Perani and colleagues (2001) demonstrated that the live observation of hand actions activates a visuo-spatial network that is involved in action representation, but observation in virtual-reality and video conditions activates lateral occipital cortices, which mainly have sensory functions. This pattern of activation suggests that the perception of actions during live observation maps onto existing action representations, but observers in virtual-reality and video conditions do not access the full motor knowledge that is available to the action observation network (AON, Perani et al., 2001). Similarly, magnetoencephalographic (MEG) recordings have revealed a stronger activation of the primary motor cortex in adult participants observing hand actions in live conditions than in video conditions (Jarvelainen, Schurmann, Avikainen, & Hari, 2001; see Shimada & Hiraki, 2006 for similar results in children). Therefore, it seems clear that the CNS does not process live and video observations similarly. Could it also be that one mode of observation favors the *learning* of a new motor skill better than the other? In addition to the theoretical interest of this question, it also has important practical implications when one considers the advances of virtual reality techniques both in teaching (Erel, Aiyenibe, & Butler, 2003; Larsen et al., 2009; Seymour, 2008) and in reeducation/rehabilitation settings (Sveistrup, 2004).

At the behavioral level, it has been suggested that live observation better promotes learning than video observation in typically developing children (Barr & Hayne, 1999; Schmitt & Anderson, 2002; Thierry & Spence, 2004; Troseth & DeLoache, 1998; Troseth, Saylor, & Archer, 2006), but no such difference has been reported for adults (Kernodle, McKethan, & Rabinowitz, 2008; Reo & Mercer, 2004). However, in both the Kernodle et al. and the Reo and Mercer studies, a combined schedule of observation and physical practice was used for the acquisition of the experimental tasks (i.e., blocks of physical practice trials were interspersed with blocks of observation trials during acquisition of the task). It is possible that the interspersing of observation with physical practice washed out the potential differences between the live and video conditions of observation. The primary goal of the present study was to determine whether live observation better promotes the learning of a complex multi-segment timing task than video observation.

In addition, in a previous video observation study (Rohbanfard & Proteau, 2011a), we showed that the observation of a model from a first-person or a third-person perspective resulted in significant learning of the task without a significant difference between the two perspectives. Although a larger activation of brain regions is not synonymous with better task learning, our finding was unexpected in light of brain imaging studies that have illustrated an increase in the activation of the contralateral pre-motor cortex during action observation from the first-person compared to the third-person perspective (Jackson, Meltzoff, & Decety, 2006; Pilgramm et al., 2010). The second goal of the present study was to determine whether we could replicate our previous finding and whether the observation media (live vs. video) would mediate it.

To reach our goals, we compared the performance of participants in four observation groups (see Method) to a physical practice and a control group. Participants were asked to complete each segment of the task in an intermediate time (IT) of 300 ms. In a pilot study, we determined the naturally emerging relative timing (Collier & Wright, 1995) that is used by individuals who physically practiced the experimental task with their right dominant hand. Specifically, three participants who did not take part in the present study were asked to complete the task in a total movement time (TMT) of 1200 ms for 60 trials; no constraints were imposed on ITs. Participants had feedback only on TMT following each trial. Twenty trials of practice allowed participants to approach the goal TMT of 1200 ms. Data from the remaining forty trials revealed a stable relative timing pattern both within and across participants. On average, participants used a relative timing of 17.2%, 29.0%, 23.2% and 30.6% to complete the first, second, third and fourth segments of the experimental task, respectively (within- and between-participant variability fluctuated between 1.0% and 2.4%; see also Blandin et al., 1999 for a similar observation).Therefore, participants in the present study were required to modify the naturally emergent relative timing pattern of the task.

It was hypothesized that the four observation groups and the physical practice group would outperform the control group. In addition, if the perception of actions maps onto existing action representations only during live observation, the live observation groups should outperform the video observation groups regardless of the observation perspective. Finally, observation from a first-person perspective would result in better learning if the primary motor cortex is more strongly activated in the first-person than in the third-person condition.

Method

Participants

Seventy-two self-declared right-handed students (35 women) from the Département de kinésiologie at the Université de Montréal participated in this study. All participants were unfamiliar with the task, apparatus and goals of the study. They had normal or corrected-to-normal vision, signed a consent form and were paid $20 CDN for their time. In addition, one author of the present paper (H. R.) served as an expert model. The Health Sciences Ethics Committee of the Université de Montréal approved this study.

Apparatus and task

The apparatus is illustrated in Figure 1. It consisted of a wooden base with three perpendicular barriers (height: 11 cm, width: 8 cm) and a start button that was embedded in a final target (11 X 8 cm). The barriers were placed perpendicular to the wooden base at the beginning of each trial to yield a closed micro switch circuit. The micro switches were connected to a computer via the I / O port of an A-D converter (National Instruments), and a millisecond timer was used to record TMT and the time that was required to complete each segment of the task (ITs). The frontal (a negative value indicates that the barrier is located to the left of the starting base) and sagittal Cartesian coordinates of the first, second and third barrier relative to the start button were -12.5 and 9 cm, -13.5 and 41.5 cm, and 0 and 29 cm, respectively. While sitting in front of the apparatus, the participant’s task was to initiate his/her movement from the starting position, trip the first, second, and third barriers successively and end their movement on the target. Participants were asked to perform each segment of the task in an IT of 300 ms, which leads to a TMT of 1200 ms.

Procedure

Participants were randomly assigned to one of six groups (7 women and 5 men per group): observers Live-1st person (L-1st), observers Live-3rd person (L-3rd), observers Video-1st person (V-1st), observers Video-3rd person (V-3rd), Physical Practice, and Control. After having been informed of the movement sequence to be performed, participants completed four experimental phases: pre-test (PRT), acquisition (ACQ), and 10-min and 24-hr retention tests (RET10 and RET24). The movement pattern, ITs and TMT were illustrated on a poster that was located directly in front of the apparatus during all experimental phases.

In the pre-test, participants performed 10 trials with their right hand without knowledge of results (KR). During acquisition, participants in the physical practice group physically practiced the task with their right hand for 40 trials. After each trial, they received KR in milliseconds (ms) of both TMT and ITs on a computer screen for 7 seconds (see Figure 1). Participants in all observation groups watched an expert model who performed the experimental task for 40 trials. The observation groups differed by the media that was used during observation (live or video) and by the observation perspective (first- or third-person). For the live observation groups, participants watched the model from either a first-person (left panel) or a third-person (right panel) perspective as illustrated in Figure 1. KR concerning the model's performance (both TMT and ITs in ms) was provided for 7 seconds on a computer screen following each trial. The model was filmed during this experimental phase from the first-person or third-person perspective when the live observation occurred from the first-person or third-person perspective, respectively. These videos were presented to the participants of the video observation groups. Each participant in the live observation groups was matched to a participant in the video observation groups. Thus, a different video was presented to each participant of the video observation groups. The video was presented on a 37-inch monitor (Sony Bravia KDL-37M3000) that was located directly in front of the participant. The monitor was calibrated so that the locations of the starting base/target and the barriers were shown in a 1:1 ratio relative to the apparatus. In each video, KR of TMT and ITs was presented after each trial in the same format and for the same duration as the presentation that was available to the live observation groups. As mentioned earlier, the model was one of the authors (H.R.) of the present paper who had practiced the task for 3,000 trials over a 15-day period. The model's performance (mean [SD] for |CE|, VE, and RMSE)[6] did not differ significantly when modeling from the first-person (|CE| = 10[6] ms; VE= 27[3] ms; RMSE= 16[1] ms) or third-person perspective (|CE|= 10[6] ms; VE= 26[4] ms; RMSE= 17[2] ms). Finally, participants in the control group had no practice in this phase. Instead, they read a newspaper that was provided to them for the same amount of time that it took the other participants to observe or perform 40 trials (approximately 10 minutes).

The two delayed retention tests (RET10 and RET24) were completed 10 minutes and 24 hours after the acquisition phase, respectively. These tests were in all points similar to the pre-test.

Data analysis

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[6]See below for the definition of each dependent variable.

The absolute value of each participant's constant error (|CE|, the constant error indicates whether a participant undershot [negative value] or overshot [positive value] the total movement time) and variable error (VE, or within-participant variability) of total movement time were calculated to determine the accuracy and consistency of the participants' movements, respectively. For intermediate times, we computed a root mean square error (RMSE), which presents in a single score how much each participant deviated from the prescribed relative timing pattern.

$RMSE = \sqrt{\sum_{Segment\,1}^{Segment\,4} \left(\frac{(ITi - 300)^2}{4}\right)}$, where *ITi* is the intermediate time of segment *i* for each trial.

The data from all phases were regrouped in blocks of five trials. The data for the three dependent variables were individually submitted to two series of analyses. First, we computed a series of analyses to determine whether observation led to significant learning of TMT and ITs. The data were submitted to an ANOVA to compare 6 Groups (physical practice, control, observers L-1st, observers L-3rd, observers V-1st, observers V-3rd) x 3 Experimental phases (PRT, RET10, RET24) x 2 Blocks (trials 1-5, 6-10) using repeated measurements on the last two factors. To determine whether some conditions of observation resulted in a better learning of the task than others, the data were submitted to an ANOVA comparing 2 Media of observation (live vs. video) x 2 Perspective of observation (1st vs. 3rd person) x 3 Experimental phases (PRT, RET10, RET24) x 2 Blocks (trials 1-5, 6-10) using repeated measurements on the last two factors.

Before computing the different ANOVAs, three specific assumptions of the ANOVA were tested. The z scores of the skewness and kurtosis values were calculated to test the normality of the distribution (Tabachnick & Fidell, 2007). To verify the homogeneity of variances, Hartley's F_{max} test was used. Finally, the degrees of freedom were adjusted as suggested by Greenhouse and Geisser (1959) when Mauchly's test of sphericity was significant. However, the original degrees of freedom were presented when the effects were significant following the Greenhouse-Geisser correction. All significant main effects and interactions were broken down using the LSD post hoc test. All effects are reported at $p < .05$.

Results

Effects of observation

The results of the first series of analyses on the RMSE and |CE| revealed significant main effects of Group, F (5, 66) = 6.51, 3.78 and Phase, F (2, 132) = 107.07, 52.11, and a significant Group x Phase interaction, F (10, 132) = 5.57, 2.48. As illustrated in Figure 2 (upper and middle panels), for both RMSE and |CE|, the breakdown of the interactions revealed no significant between group differences in the pre-test, Fs < 1. In the 10-min retention test, the control group had a significantly larger RMSE and |CE| than all of the other groups. Moreover, the physical practice group had a significantly smaller RMSE than the four observation groups, which did not differ significantly from one another (RMSE= 116, 64, 66, 63, 67, and 47 ms for the control, L-3rd, L-1st, V-3rd, V-1st, and PP, respectively). However, the physical practice group did not significantly outperform the four observation groups for |CE| (302, 80, 79, 85, 86, and 101 ms for the control, L-3rd, L-

1st, V-3rd, V-1st, and PP, respectively). In the 24-hr retention test, the control group had a significantly larger RMSE and |CE| than the five remaining groups, which did not differ significantly from one another, F (5, 66) = 11.80, 7.51, respectively. Figure 2 (upper and middle panels) also illustrates that all experimental groups, except the control group, had a significantly reduced RMSE and |CE| from the pre-test to the other two experimental phases. It is also worth noting that there was a significant increase in RMSE and |CE| between the 10-min and the 24-hr retention test for the physical practice group ($ps \leq .02$) but not for the four observation groups ($ps \geq .12$). However, the physical practice group did not differ significantly from the observation group in the 24-hour retention test.

The results of the ANOVA computed on VE revealed significant main effects of Phase, F (2, 132) = 59.22, and Block, F (1, 66) = 10.66. Post hoc comparisons revealed that VE significantly decreased from one experimental phase to the next (67 ms, 48 ms, and 38 ms for the PRT, RET10, and RET24, respectively). Moreover, participants had a larger VE in block 1 (54 ms) than in block 2 (49 ms).

Effects of media and perspective

The results of the second series of analyses revealed no significant main effect or interaction for RMSE (all ps>.23). Concerning |CE| and VE on TMT, the ANOVAs revealed a significant main effect of Phase, F (1, 44) = 10.01, 20.09. Post hoc comparisons revealed that |CE| significantly increased from the 10-min to the 24-hr retention test (83 ms and 112 ms, respectively),[7] but VE significantly decreased (47 ms and 36 ms, respectively) from the 10-min to the 24-hr retention test.

Discussion

In the present study, we investigated the effects of a live versus video observation from a first-person or third-person perspective on the learning of a four-segment sequential timing task. The results of the two retention tests revealed that all observation groups, regardless of the medium (live vs. video) or perspective (first-person vs. third-person) significantly outperformed the control group on both total movement time and intermediate times. This finding is consistent with previous research showing that observation leads to significant learning of the task (e.g., Bird & Heyes, 2005; Blandin et al., 1999; Blandin & Proteau, 2000; Buchanan & Wright, 2011; Hayes et al., 2010; McCullagh & Weiss, 2001; Osman et al., 2005; Rohbanfard & Proteau, 2011a, b; Shea, Wright, Wulf, & Whitacre, 2000; Wulf & Mornell, 2008; Wulf, Shea, & Lewthwaite, 2010).

However, the data from the present study revealed no significant differences related to the observation medium (live vs. video) in the learning of the task. This finding is consistent with previous behavioral studies of the effectiveness of these two media in adult participants (Kernodle et al., 2008; Reo & Mercer, 2004) but not in typically developing children (Barr & Hayne, 1999; Schmitt & Anderson, 2002; Thierry & Spence, 2004; Troseth & DeLoache, 1998; Troseth et al., 2006). As already advocated (Barr & Hayne, 1999), it is likely that children pay less attention to a model that is presented by video than

[7]It should be noted that the inclusion of the control and physical practice groups in the first series of analyses masked this increase in |CE| between the 10 min and 24 hour retention tests.

to a live model, but adult participants are able to deal equally well with the video and live presentations of a model to improve their learning.

This last finding from the present study is inconsistent with the predictions of neuroimaging studies (Ferrari, Gallese, Rizzolatti, & Fogassi, 2003; Jarvelainen et al., 2001; Perani et al., 2001; Shimada & Hiraki, 2006). For example, only movements in a live observation condition can be mapped onto existing action representations (Perani et al., 2001), and live observation results in a stronger activation of the primary motor cortex than video observation (Jarvelainen et al., 2001). Moreover, mirror neurons in monkeys are activated when movements are observed in a live condition but not when they observed by video presentations (Ferrari et al., 2003). Taken together, these findings suggested that live observation is more beneficial than video observation. This was clearly not the case in the present study. There are several possible reasons for this discrepancy. First, it could be that recognition is better, and therefore, the AON is more active during live vs. video observation (small screens are often used during video observation). It could also be that the AON is more active during live than video observations because in the former condition, the observer is more likely aware of the model's state of mind and reactions to his or her performance. In that regard, the AON is involved not only in the understanding of the model's action (for reviews, see Rizzolatti & Craighero, 2004; Rizzolatti, Fogassi, & Gallese, 2001) but also in the detection of the other's emotions and thoughts/intentions (e.g., Carr et al., 2003; Decety & Grèzes, 2006; Jackson, Meltzoff, & Decety, 2005; Singer, 2006; Wicker et al., 2003). Conversely, because video observation is often restricted to a smaller visual field than live observation, it can focus the observer's attention on the relevant stimuli while decreasing their tendency to attend to irrelevant stimuli (Charlop-Christy, Le, & Freeman, 2000; Corbett, 2003), which eliminates unnecessary information processing in the observer's AON. All of these propositions add up to one important practical conclusion: the larger activation of brain regions does not necessarily result in a better learning of a motor task.

Concerning the perspective of observation, the present data replicated the results of Rohbanfard and Proteau (2011a; see also Ishikura & Inomata, 1995; Sambrook, 1998) revealing that the observation of a model from the first-person or third-person perspective resulted in no significant differences in the learning of both TMT and ITs of the task. The results of the present study add to this finding by showing that this is the case for both live and video observation. Again, these results are somewhat inconsistent with findings from brain imaging studies showing a larger activation of the pre-motor cortex for movements observed from a first-person compared to a third-person perspective (Jackson et al., 2006; Pilgramm et al., 2010). A possible explanation for this divergent finding is that, in the present study, learning was evaluated during two delayed retention tests (10 min and 24 hr), but neuroimaging studies have recorded the activation of the observers' brain simultaniously with action observation. It is generally well accepted that the activation of the AON at least partly reflects recognition of what is observed. For example, familiarity with the observed movement has a significant effect in action understanding (Calvo-Merino, Glaser, Grezes, Passingham, & Haggard, 2005; Calvo-Merino, Grèzes, Glaser, Passingham, & Haggard, 2006).Therefore, in these neuroimaging studies, the larger activation of the AON during observation from the first-person compared to the third-person perspective could have resulted from the natural and more familiar situation (Pilgramm et al., 2010). However, our results suggest that the observation perspective does not influence the learning of a new motor skill when this skill has to be performed either 10 minutes or 24 hours after observation.

It is worth noting that the lack of significant differences between the four observation groups was not a result of a floor effect. First, the physical practice group outperformed the observation groups on intermediate times of the task in the 10-min retention test. Second, the expert model (|CE| = 10 ms, VE = 27 ms, and RMSE = 17 ms) had a better performance compared to the physical practice group and the four observation groups (|CE| = 80-120 ms, VE = 35-50 ms, and RMSE = 50-65 ms). Therefore, there was still room for improvement.

Finally, the results of the 10-min retention test revealed that the physical practice group outperformed all observation groups on the intermediate times of the task, but no such between-group differences were noted on TMT. These results suggest that the observers first learned to complete their movements in the prescribed TMT and then learned the relative timing pattern of the task (see Blandin et al., 1999, for similar results). However, these findings differ from the results of a previous study (Rohbanfard & Proteau, 2011a) in which we used the same experimental task but showed that observation permitted participants to concomitantly learn TMT and ITs. The only procedural difference between the two studies is that, in the present study, observers were shown a single model (as in Blandin et al., 1999), whereas in our previous work, we used a mixed observation of novice and expert models. This suggests that mixed observation of novice and expert models engages one in different information processes than the observation of only an expert model. In support of that proposition, we (Rohbanfard and Proteau, 2011b) recently had participants observe a novice, an expert, or a combination of trials performed by an expert and a novice model while performing the same experimental task as in the present study. The results of an immediate retention test revealed that the novice-observation and expert-observation groups first learned TMT and then ITs, but the mixed-observation group concomitantly learned TMT and ITs. We propose that the observation of either expert or novice model leads to the development of a “standard of reference” and “error detection correction mechanisms,” respectively, but the observation of the mixed model results in the development of both processes. As a result, observers of a mixed model are more actively engaged in processing the available information, which allows them to simultaneously pay attention to and, therefore, learn both aspects of the experimental task (i.e., TMT and ITs).

Our findings have implications in a number of practical settings, such as the teaching of sport-related motor skills, physical therapy exercises, and surgical procedures. Our results suggest that live observation can be replaced by a video presentation technique and result in similar learning benefits. Using a video has the obvious advantages of convenience and consistency. A single video can easily be used by a large number of participants at different places and times. In addition, video observation is a more cost- and time-efficient technique than live observation (Charlop-Christy et al., 2000).

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Figure captions

Figure 1. Top view of the apparatus and perspective-taking conditions used in the study. Participants observed a model live (live observation groups) or on a video (video observation groups) from a first-person (left panel) or a third-person (right panel) perspective.

Figure 2. Absolute constant error (|CE|) and variable error (VE) on total movement time and root mean square error (RMSE) on intermediate times as a function of experimental phases for the physical practice (PP), control, and four observation groups (L-3rd = Live/3rd person, L-1st = Live/1st person, V-3rd = Video/3rd person, V-1st = Video/1st person). Error bar illustrates the standard error of the mean.

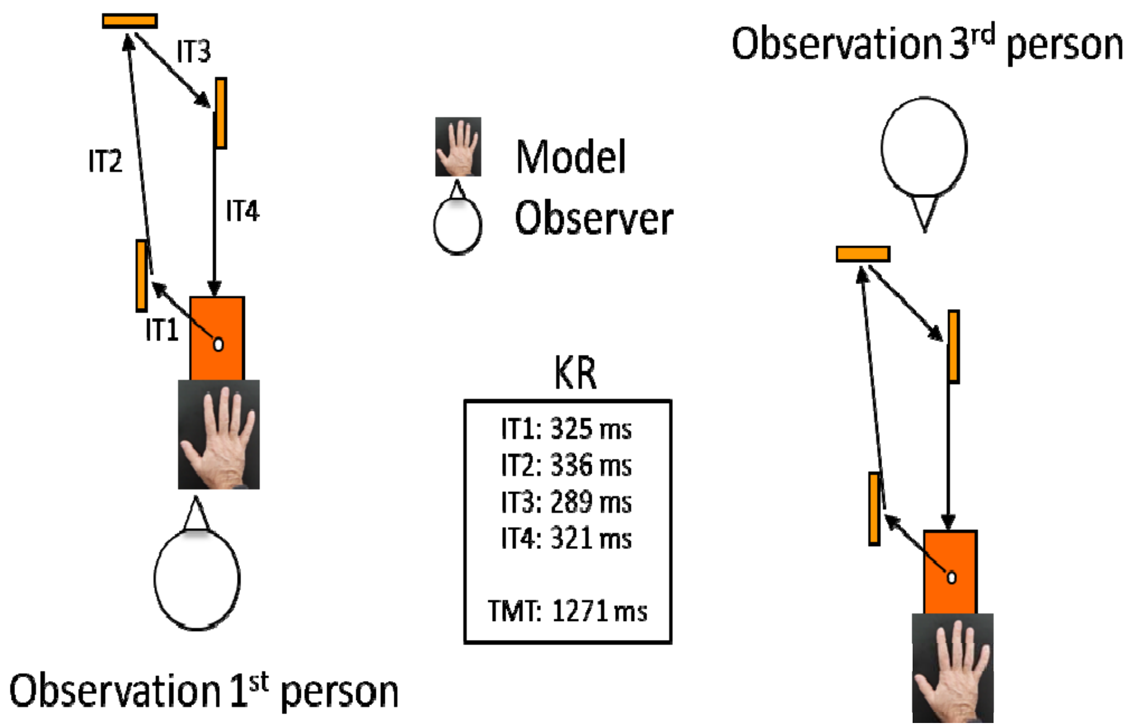
Observation 3rd person
IT3
IT2
IT4
IT1
Model
Observer
KR
IT1: 325 ms
IT2: 336 ms
IT3: 289 ms
IT4: 321 ms
TMT: 1271 ms
Observation 1st person

Figure 1

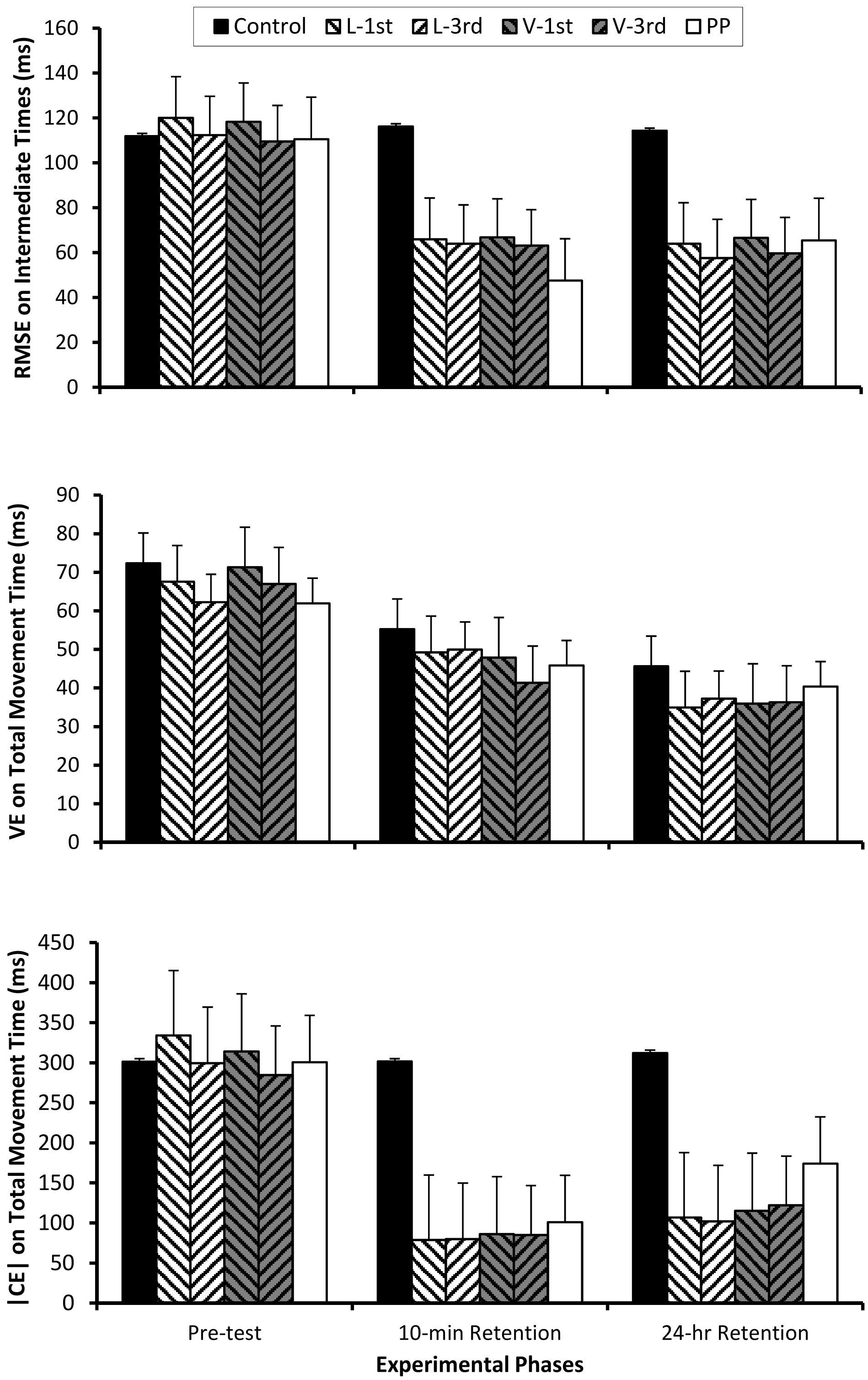
Control
L-1st
L-3rd
V-1st
V-3rd
PP
RMSE on Intermediate Times (ms)
160
140
120
100
80
60
40
20
0
VE on Total Movement Time (ms)
90
80
70
60
50
40
30
20
10
0
|CE| on Total Movement Time (ms)
450
400
350
300
250
200
150
100
50
0
Pre-test
10-min Retention
24-hr Retention
Experimental Phases

Figure 2

Chapter 5 : General discussion

Motor skills are essential components of daily life activities; and observation has been shown to be a very effective strategy to promote the learning of motor skills (Williams & Hodges, 2005). During observation, learners selectively take in information about spatial and/or temporal features of a motor task, resulting in the formation of a cognitive representation of what is to be performed. In the present thesis, we aimed to determine whether some models or conditions of observation better promote motor learning than others.

In the first study, we wanted to determine whether observation of a combination of expert and novice models (i.e., a mixed model) better promotes learning of a timing task than observation of either an expert or a novice model. Next, we wanted to determine whether there is an optimal type of mixed model. Specifically, three different types of novice models (i.e., highly variable, and with or without an increase in performance during practice) were individually combined with an expert model, thereby enabling us to investigate whether a specific type of novice model in a mixed observation schedule would result in better learning of the task. In our second study, we investigated whether observing a same-handed model (e.g., right-handed observer watching right-handed model) better promotes learning in comparison to the observation of an opposite-handed model (e.g., right-handed observer watching left-handed model), and whether the first-person (both the observer and the model placed in the same perspective) and third-person (the observer facing the model) observation perspectives have differential impacts on the observational learning of our experimental task. Finally, in our third study, we investigated the effects of live vs. video observation on learning of the task. In addition, we sought to determine whether these modes of observation are mediated by the observation perspective.

As expected (for reviews on observational learning, see Ferrari, 1996; Hodges et al., 2007; McCullagh & Weiss, 2001; Vogt & Thomaschke, 2007; Wulf & Mornell, 2008), the results of all studies presented in this thesis revealed that all observation groups outperformed the no-practice control group. Clearly, this indicates that observation, regardless of the model's skill level, model's handedness, observer's perspective, and type of media used, resulted in significant motor learning; however, some conditions better promoted learning than the others.

Model's skill level

Previous observational learning studies have shown that observation of an expert model promotes motor skill learning presumably because it enables the observer to develop a "perceptual blueprint" of the observed task (Sheffield, 1961) that serves as a standard of reference against which the participant's performance is compared (Bandura, 1977, 1986). In addition, observation of a novice model has been shown to enhance learning of a motor task, probably because it results in the development of "error detection and correction" mechanisms in the observer (Adams, 1986; Badets et al., 2006; Black & Wright, 2000; Black et al., 2005; Blandin & Proteau, 2000; Carroll & Bandura, 1990).

The results of our first study contribute to this literature by showing that a mixed schedule of observation in which the observer watches a short series of trials performed in succession by a novice and by an expert model led to better learning of the experimental task. We argue that observing both types of models and thus being able to compare the expert and the novice performance likely permitted participants to detect errors in the novice model performance and determine how to avoid/correct them. This comparison between what needed to be done and typical errors was not possible for participants who observed only an expert or a novice model.

Nonetheless, the advantages of the mixed observation condition became manifest in a transfer test that required participants to maintain the rhythmical structure of the movement but to change its overall duration (i.e., 1500 ms task). We speculate that observation of a mixed model might enable the observer to experience a wide range of movement patterns, from the near-perfect (i.e., expert performances) to the poorest movements (i.e., novice performances), resulting in the development of a more generalized movement representation than the other types of observation. In the case of expert or novice observation, the participants observe a more limited range of movement patterns, which might result in limited or more specific learning of the task. This is consistent with the predictions of the motor schema theory (Schmidt, 1975), which suggests that transfer to a novel parameterization of a generalized motor program (GMP) is facilitated following practice involving many parameter variations of the GMP (i.e., variable practice) as opposed to practice involving only one or a limited number of parameter variations (i.e., non-variable practice). This could explain why participants in the mixed observation group better generalized their learning from the 1200 ms to the 1500 ms imposed TMT than observers of a novice or an expert model. Practically, these results suggest that mixed observation should be preferred in open skills learning, which requires trial-to-trial changes in movement parameterization (Galligan, 2000; Magill, 2007; Schmidt & Wrisberg, 2008).

In addition, we found that learning did not significantly differ between conditions in which the novice model improved or not his performance or performed highly variable during practice. This suggests that it is the comparison between a near-perfect performance (i.e., expert model) and one showing large errors (i.e., novice model), rather than the type of novice model, that is the most critical determinant of the effectiveness of a mixed model. Finally, it can be argued that any combination of two models, such as two novices or two expert models, might be better than observation of a single model because it provides the observer with a form of variable practice, which has been shown beneficial for observational learning of a motor skill (Blandin et al., 1994; Buchanan & Dean, 2010). Future research is needed to deal with this issue.

It is worth noting that the learning of the experimental task did not differ significantly following physical practice or observation of a mixed model. This was not the case, however, for the comparisons between the physical practice and observation of either expert or novice models. Thus, it appears that the mixed observation schedule engages the observer in processes more similar to those experienced during physical practice than the two other observation regimens.

Model's handedness

In real-life situations, a right-handed pupil often observes a right-handed coach or instructor performing the skill that he or she wants to learn (i.e., a same-handed model); however, in some cases, an individual may observe an opposite-handed model, such as when a left-handed trainer shows a right-handed pupil how to putt or drive a golf ball. The results of the second study of this thesis revealed that right-handed participants benefitted more from observation of a same-handed model (i.e., right-handed model) rather than of an opposite-handed model (i.e., left-handed model), regardless of the observer's viewpoint. This is in contradiction with TMS and brain imaging studies that illustrate a larger activation of the ipsilateral brain areas for the movements observed from a third-person perspective (Alaerts et al., 2009; Hesse et al., 2009; Kilner, Marchant, & Frith, 2009; Shmuelof & Zohary, 2008). In addition, an observer imitates the actions of others in a mirror-imaged manner when observed from a third-person perspective (Avikainen, Kulomaki, & Hari, 1999; Chiavarino, Apperly, & Humphreys, 2007; Iacoboni et al., 2001). Taken together, these studies suggest that observation of an opposite-handed model from a third-person perspective should have facilitated learning in observers. This was not the case in our study, however. Thus, it seems that action observation or immediate imitation of the observed movements is quite different from learning a complex spatiotemporal pattern, as in the present study and as in most sport-like activities. It could be that the intent of learning might require the action observation network (AON) to transform the visual information to fit with how the observer will have to perform the task. This transformation is likely easier to do or more natural when observing a same-handed model. This position concurs with recent evidence suggesting that the AON is linked to or comprised of sensorimotor regions of the brain that simulate motor programming as if the observed movement was to be performed with one's dominant hand (Neal & Kilner, 2010; Press et al., 2011; Wakita & Hiraishi, 2011; Willems & Hagoort, 2009).

Nonetheless, there is an alternative explanation of our findings that needs to be considered. It could be that the better learning revealed by observers of a same-handed model, as opposed to an opposite-handed model, resulted from differences in the task they observed and performed rather than the model's handedness. In our study, all participants were required to perform the experimental task with their right dominant hand on the right apparatus, as was the case for the right-handed model. However, the left-handed model was performing the task with his left hand on the left apparatus, which was a mirror image of the right apparatus (see Fig. 1 in Chapter 3). Therefore, during observation of an opposite-handed model, participants were provided with the same pattern of muscle (motor) activation but a different spatial-temporal pattern required for performing the right-hand movement. Thus, it could be that participants coded the movement sequence in a visual-spatial coordinate system (see Boutin et al., 2010; Gruetzmacher et al., 2011) rather than in a motor coordinate system. Future research is needed to resolve this question.

Regardless of whether the observer learns motor coordinates or visual-spatial coordinates, the findings of our study have important implications in a number of practical settings, such as teaching sport-related motor skills, rehabilitation exercises, and surgical procedures. For example, when learning how to drive/putt a golf ball or serve in badminton or tennis, right-handed pupils would observe a right-handed trainer/instructor for better learning of the task, no matter whether the observation took place from a first- or third-person perspective.

Perspective and medium of observation

The results of the second and third studies of this thesis revealed that the first- and third-person observation perspectives resulted in no significant differences in the learning of the experimental task. These findings were unexpected in light of brain imaging studies that have illustrated for right-handed participants, a larger activation in the left sensorimotor cortex during action observation from the first-person than from the third-person perspective (Jackson, Meltzoff, & Decety, 2006; Pilgramm et al., 2010). In addition, the results of the third study revealed no significant differences related to the medium of observation (i.e., live vs. video). Again, this is inconsistent with the predictions of brain imaging studies which generally suggest that live observation would be more beneficial than video observation (Ferrari et al., 2003; Jarvelainen et al., 2001; Perani et al., 2001; Shimada & Hiraki, 2006). A possible explanation for the discrepancy between our results and those of the above-mentioned brain imaging studies could be that the activation of the AON recorded in the neuroimaging studies reflects the recognition of what is observed, which might be affected by a variety of factors. For instance, it has been shown that one's familiarity with the observed movement has a significant effect in action recognition/understanding (Calvo-Merino et al., 2005; Calvo-Merino et al., 2006). Because the actions being observed in the brain imaging studies have been experienced often by the participants, it is possible that the larger activation revealed for the first-person perspective could have resulted from the situation being more natural and familiar than for the third-person perspective (Pilgramm et al., 2010). In our studies, however, we used a complex spatial-temporal task that was completely new for the participants. Moreover, it seems that recognition is better, and thus the AON is more activated, during live than during video observation in the brain imaging studies because, for example, small screens are often used during video observation. However, we used a large screen in our study so that the participants in the video condition observed the model's movements in an approximately 1:1 ratio relative to the live observation.

In addition, there is one main procedural difference between the present studies and the previously mentioned brain imaging studies. In neuroimaging studies, the activation of the observers' brain was recorded *during* action observation, whereas we measured *learning* in two delayed retention tests (10-min and 24-hr). Therefore, the differential effects of various observation perspectives and mediums could be true only for the observation period, which is a short-term *performance* effect. The results of the 10-min and 24-hr retention tests used in our studies, however, revealed that the observation perspective or medium did not influence *learning* of the task. This proposition is well supported by the results of a previous study (Ishikura & Inomata, 1995) showing that although observation from a first-person perspective resulted in better performance than a third-person perspective, it resulted in similar long-term retention and, thus, learning of the task. Therefore, it seems that during memory consolidation, participants are able to process the information required for learning of the task, with no significant differences attributed to the perspective or medium of observation. All of these propositions add up to one important practical conclusion: the larger activation of brain regions revealed in the brain imaging studies does not necessarily result in better learning of a motor task. Future studies should focus on differentiating between the *performance* and *learning* effects of different observation conditions.

From a practical point of view, our results suggest that a video presentation can be used successfully with the obvious advantages of convenience, consistency, and time or cost efficiency. In addition, it simplifies the presentation of mixed models, which we have shown to be most efficient to promote motor skill learning. With video, many different combinations/editions of the original performances can also be reproduced easily. Finally, in light of the results of our second study, a left-handed teacher/instructor would be well advised to use a video presentation of a right-handed model when teaching a motor task to right-handed participants.

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