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Claire Calmels, Paul Holmes, Lopez Emilie, Véronique Naman

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A Chronometric Comparison of Actual and Imaged Complex Movement Patterns

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Claire Calmels

8

Institut National du Sport et de l'Éducation Physique, Paris, France

9

Paul Holmes

10

Research Institute for Health and Social Change, Manchester Metropolitan University, UK

11

Emilie Lopez

12

Institut National du Sport et de l'Éducation Physique, Paris, & UFRSTAPS Besançon, France

13

Véronique Naman

14

Institut National du Sport et de l'Éducation Physique, Paris, France

15

16 Correspondence concerning this article should be addressed to Dr Claire Calmels,

17 Département des Sciences du Sport, Institut National du Sport et de l'Education Physique,

18 11 Avenue du Tremblay, 75012 Paris, France. E.mail: claire.calmels@insep.fr

19 Telephone number: (33-1) 41 74 45 77

20 Fax number: (33-1) 41 74 45 35

21

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Author Notes

Claire Calmels, Institut National du Sport et de l'Éducation Physique, Paris, France

Paul Holmes, Research Institute for Health and Social Change, Manchester
Metropolitan University, UK

Emilie Lopez, Institut National du Sport et de l'Éducation Physique, Paris, &
UFRSTAPS Besançon, France

Véronique Naman, Institut National du Sport et de l'Éducation Physique, Paris, France

Correspondence concerning this article should be addressed to Dr Claire Calmels,
Département des Sciences du Sport, Institut National du Sport et de l'Education Physique,
11 Avenue du Tremblay, 75012 Paris, France. E.mail: claire.calmels@insep.fr
Telephone number: (33-1) 41 74 45 77
Fax number: (33-1) 41 74 45 35

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Abstract

The aim of this study was to consider the functional equivalence of internal imagery, external imagery and action execution. Sixteen elite gymnasts imaged and performed a complex gymnastic vault. Ten performers imaged from an internal perspective and six used an external perspective. Whilst the results revealed that the time to image the entire motor task was not significantly different from the time required to physically perform it, irrespective of the imagery perspective employed, the temporal organization of the action *was* different within the imagery conditions compared to the physical condition. The results do not provide support for the principle of temporal functional equivalence and are discussed in the light of recent findings from the cognitive neuroscience and psychology literature.

Author key-words: principle of functional equivalence, timing paradigm, temporal organization, imagery perspectives, complex motor task

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1 Introduction

2 The neuroscience and psychophysiology literature has suggested a functional
3 equivalence between action execution, motor imagery and action observation (Crammond,
4 1997; Decety & Grèzes, 1999; Grèzes & Decety, 2001, Grèzes, Fonlupt, & Decety, 2000;
5 Jeannerod, 1999). The principle of this functional equivalence suggests that similar neural
6 processes are involved in the physical execution, mental simulation and observation of an
7 action, since each operation is proposed to be assigned to the same internal brain
8 representation (Jeannerod, 1994; Jeannerod, 1999).

9 At a behavioral level, functional equivalence has been considered through timing
10 paradigms by comparing the time taken to physically complete an action with the time
11 required to mentally perform the same task (see Guillot & Collet, 2005 for a review). A
12 number of studies have shown that motor rules evident for physical actions (e.g., Fitts' Law
13 and The Isochrony Principle) are also maintained during imagery conditions for laboratory-
14 based tasks (Cerritelli, Maruff, Wilson, & Currie, 2000; Decety & Jeannerod, 1996; Decety &
15 Michel, 1989; Maruff et al., 1999).

16 Durations of mental movements have been shown not to differ significantly from those
17 of physically executed movements for participants. For example, performing a locomotion
18 task with a specific itinerary (Decety, Jeannerod, & Prablanc, 1989) or an unfamiliar cyclical
19 motor task such as pedalo (Munzert, 2002); executing a graphic gesture (Decety & Michel,
20 1989); performing hand/arm movements (Parsons, 1994); completing arm movements in
21 sagittal and horizontal planes under different loading conditions (Papaxanthis, Scieppati,
22 Gentile, & Pozzo, 2002); and executing whole-body movements after a long exposure to
23 microgravity (Papaxanthis, Pozzo, Kasprinski, Berthoz, 2003) have all been shown to have
24 temporal congruence between actual and imagined movement. However, in some cases,
25 mental and physical durations do differ. The temporal differences have been attributed to

1 external factors such as: mass (Cerritelli et al., 2000; Decety et al., 1989); the difficulty of the
2 task (Decety, 1991); biomechanical constraints (Parsons, 1994); and the nature of the skill
3 (Mackay, 1981). Extended time for mental execution of an action has been found in
4 comparison to the physically task time. This was observed when participants performed tasks
5 under imagined loaded conditions (Cerritelli et al., 2000; Decety et al., 1989) and during
6 actual performance on a beam walking task after having simulated it (Decety, 1991). In the
7 latter case, the time to mentally complete the task also increased with the difficulty of the task
8 (i.e., reducing the width of the beam). In contrast, actual movement duration was found to
9 exceed imagined movement duration for uncommon hand orientations and uncomfortable
10 kinesthetic sensations (Parsons, 1994) and for skill in speech production (Mackay, 1981).

11 A number of explanations have been offered for the disparity between mental and
12 actual durations. In tasks concerning carrying weights, Decety et al. (1989) and Jeannerod
13 (1994) have suggested that during imagery conditions, individuals perceive extra force as an
14 increase in duration. In tasks involving unfamiliar actions, Parsons (1994) has proposed that
15 the imagery process is incapable of completely taking into account the characteristics of
16 unfamiliar postures and that this may explain the generation of sketchy and rapid simulations
17 for such tasks. In speech production tasks, Mackay (1981, 1982) suggested that reading a
18 sentence mentally, as quickly as possible, was faster than saying it overtly because it did not
19 involve full recruitment of the motor system. Linked to this idea, physically producing an
20 action prior to starting imagery of the same action might promote greater additional
21 kinesthetic awareness and, potentially, alter the timing of the image. Research findings in this
22 area have been contradictory. Coello and Orliaguet (1992) showed that, for novice golf
23 players, the duration of an imaged movement did not vary whether or not there were
24 preliminary physical executions of the movement. In contrast, Decety (1991) found the
25 opposite for undergraduate students who had to walk on wooden beams of different width.

1 It seems that the time to execute a mental action is related to the time needed to
2 actually perform the same action but that this relationship is complicated. When durations of
3 actions are expressed as a function of the durations of imagined movements or vice-versa
4 (Cerritelli et al., 2000; Decety et al., 1989; Mackay, 1981) a close correlation is seen.

5 Chronometric studies have tended to compare actual and mental durations of entire
6 actions. Simple motor skills such as locomotion tasks, visually-guided pointing tasks, arm and
7 hand movements and graphic movements have been used. More recently, in the sport domain,
8 Calmels and Fournier (2001), Le Her, Hertogh, and Garzaro (1997), Minvielle-Moncla,
9 Ripoll, and Audiffren (2003), and Reed (2002) have considered more complex, whole body
10 tasks. In these studies, the time to imagine a performance was quicker than that of the actual
11 performance. They also reveal that the relationship between actual and simulated movement is
12 modified by the complexity of the skill or the participants' expertise (e.g., Reed, 2002). Reed
13 has suggested that task complexity has an effect on the imagery-action relationship; as
14 rotational complexity increased, imaged times increased relative to the physical times. She
15 also proposed that temporal discrepancies between imagined and actual behavior may be a
16 consequence of schematic differences in skill representation since expertise modifies the
17 cognitive organization of a skill (Karmiloff-Smith, 1990). In Reed's (2002) study, the divers
18 did not possess the same level of expertise and their knowledge about how to perform dives
19 may not have been similar, resulting in different imagery times. Intermediate divers took
20 longer to develop dive elements for imagined performance in comparison to expert divers, for
21 whom element assemblage was suggested to be automated. In contrast, novice divers had
22 faster imagery times than intermediate divers because they possessed less fundamental
23 technical knowledge concerning diving.

24

1 Dividing an action into discrete temporal epochs allows examination of the duration of
2 the different stages of an action under imagined and actual conditions. This provides the
3 opportunity to appraise the time course of mental processing. It also allows consideration of
4 the mechanisms involved as individuals perform an action under different conditions. More
5 specifically, investigating whether different conditions of generating an action (i.e., actually
6 or mentally) modify the temporal organization of the stages that constitute this action.

7 To our knowledge, this kind of temporal division of an action has only been
8 considered in three studies: Calmels and Fournier, (2001); Minvielle-Moncla et al., (2003);
9 and Reed, (2002). These studies showed that during imagery conditions, there was temporal
10 disruption of the different stages of an action. Participants performed significantly faster in
11 imagery than during the physical conditions. Unfortunately, in two studies of the studies, the
12 visual perspective used in the imagery condition was not specified. This is important, because
13 if, as Farrer and Frith (2002) have shown, changed visual perspective is associated with a
14 different neural expression, it is possible that temporal components of a task are also
15 modified.

16 To obtain a greater understanding of the temporal relationship between mental and
17 actual representation activity, investigating the visual perspective characteristics of imagery
18 that effect their functional equivalence may prove fruitful (see Holmes & Collins, 2001 for a
19 review). In the studies discussed above, and as reported by Ruby and Decety (2001) and
20 Sirigu and Duhamel (2001), where imagery perspective has been specified, imagery was
21 reported to be performed from an internal, first-person perspective (i.e., imaging the execution
22 of a skill as if looking through one's own eyes). However, in the sport psychology literature,
23 researchers have referred to imagery from two perspectives: a first-person and a third-person
24 perspective (i.e., viewing movement from the perspective of an external observer) (see Hardy
25 & Callow, 1999; White & Hardy, 1995).

1 The two perspectives seem to be controlled by different processes (e.g., Farrer & Frith,
2 2002). Brain areas activated during a first-person perspective, as revealed through positron
3 emission tomography (PET), do not match those activated during a third-person perspective
4 (Decety et al., 1994). The former has been proposed to “rely on motor-kinesthetic information
5 processing” whereas the latter “rely more on visuospatial processing” (Decety, 1996, p.46)
6 and do not preferentially use motor mechanisms (Sirigu & Duhamel, 2001). Ruby and Decety
7 (2001) have also shown that whilst imagery an action from a first and third-person perspective
8 activated common brain areas (i.e., SMA, the precentral gyrus, the precuneus, and the
9 occipito-temporal junction) further specific activity was observed in the third-person
10 perspective (right inferior parietal cortex and precuneus) and during a first-person perspective
11 (left inferior parietal cortex and somatosensory areas). In support of the evidence for some
12 perspective specificity, Fourkas, Avenanti, Urgesi, and Aglioti (2006) have provided evidence
13 that imagery of a movement increased corticospinal excitability and that this excitability was
14 greatest during a third-person perspective in comparison to a first-person perspective.

15 If neural correlates are associated with temporal patterning of behavior then these
16 structural differences suggest that the timing of different imagery perspective may also be
17 different. If the third-person perspective relies on more spatial processes (Decety, 1996;
18 Sirigu & Duhamel, 2001), mental simulation may be faster than actual execution because it
19 does not seem to evoke motor processing (Mackay, 1981, 1982). Following a similar line of
20 argument, imagined movements performed from a first-person perspective should have a
21 temporal pattern closer to that of the physical movement because the motor representations
22 employed are similar to those activated during physical execution of the action with the
23 exception of motor output (Jeannerod, 1997). Whilst not directly linked to temporal
24 patterning, the case for a first-person perspective has also been shown by Wang and Morgan
25 (1992). Their study of visual perspective effects on imagined exercise demonstrated that

1 ventilation and effort sense were higher when an internal imagery perspective was employed
2 compared to an external imagery perspective. Despite some observed similarities between
3 internal and external conditions in metabolic and cardiovascular responses, the authors
4 concluded that internal imagery had the closest resemblance to actual exercise.

5 It was of interest, therefore, to examine the temporal functional equivalence for a
6 complex task during imagery from an internal visual perspective (i.e., first-person
7 perspective) and also from an external visual perspective (i.e., third-person perspective).
8 Consideration of the temporal organization of a complex task under these conditions was
9 proposed to reveal information relating to motor control processes and further increase
10 understanding of the relationship between mental and actual behavior duration.

11 It was predicted that an internal visual perspective would show greater temporal
12 functional equivalence with the physical condition compared to the external visual perspective
13 for the full action. The external visual perspective was hypothesized to show significantly
14 faster times than the internal perspective and the actual action times. No *a priori* hypotheses
15 were offered concerning the temporal organization of the complex task under imagined and
16 actual conditions, since there was insufficient literature to support informed predictions.

17 Gymnastics routines offer diverse elements executed by the whole body around
18 longitudinal, transversal and/or lateral axes. An exercise on the vault was chosen because of
19 the ease with which routines can be broken down into clearly defined, recognized stages.
20 Each stage is interpreted in the same way for each gymnast and so provides easily accessible
21 epochs for comparison. In addition, using elite female athletes as participants offers a high
22 level of ecological validity and population rarely seen in the psychology literature.

Method

Participants

Seventeen female artistic gymnasts aged between 12 and 18 years (mean age = 14.5, SD = 1.63 years) participated in the study. One participant was removed from the experiment since she did not meet the imagery requirements (see Procedure section). All the gymnasts competed at national level and comprised the entire junior French team. Each gymnast participated in at least 25 hours of physical training per week and had been supported by sport psychology training for at least three months. Separate written informed consent was obtained from the gymnasts and their parents.

Experimental Task

The study required the gymnasts to execute a Yurchenko vault. This involved rotating the whole body around both longitudinal and transversal axes. The vaulting exercise comprises a 25 meter-run-up to a springboard (Stage 1). The gymnast lands two-footed on the springboard to gain height and moves through the air towards the vault box (Stage 2). The hands are placed on the vault box before pushing off (Stage 3) to allow the gymnast to land on the mat (Stage 4) (see Figure 1.). The Yurchenko vault was chosen since it was considered as a complex routine because of the inclusion of a round off entry and a backward somersault only able to be performed by elite gymnasts. All the participants in this study had successfully completed a Yurchenko vault prior to the study and had included it in their performance repertoire in a major competition.

Materials

Pre-experimental questionnaires. In order to determine the participants' preferred imagery perspective, three methods were used: the French version (Fournier, Le Cren, & Monnier, 1994) of the Vividness of Movement Imagery Questionnaire (VMIQ) (Isaac, Marks, & Russell, 1986); verbalized reports from the gymnasts that related to the imagery perspective

1 they employed in their training and competitive pre-vault preparation; and assessment from
2 each gymnast's sport psychologist. The VMIQ 24-item questionnaire uses a 5-point Likert-
3 type scale to measure the imagery vividness of a number of movements from two visual
4 perspectives. First, when a movement is imaged from an external visual or third-person
5 perspective (TPP), and second, when it is imaged from an internal visual or first-person
6 perspective (FPP). Scores range from a low of 24 to a high of 120 for each perspective. A low
7 rating (24-48) indicates low imagery vividness, whereas a high rating (96-120) indicates high
8 imagery vividness (Goginsky, 1992). The VMIQ assessment of the preferred imagery
9 perspective only monitors the quality of the image content in terms of its vividness. To reduce
10 the emphasis placed just on vividness, gymnasts were also questioned about the imagery
11 perspective they used during vault training sessions and in competition. Independent reports
12 by the gymnast's sport psychologist were also collected. The participants were instructed to
13 employ the perspective that scored highest on the VMIQ and concurred with their own reports
14 and those of their sport psychologist.

15 *Post-experimental questionnaires.* This session comprised two parts. First, as
16 recommended by Goginsky and Collins (1996), full manipulation checks and debriefs
17 followed the experimental sessions through self-report questionnaires and discussion with the
18 gymnasts. Full manipulation checks and debriefs were used to ensure that the participants
19 were not estimating the time or counting during the period when they were imaging.
20 Clarification was also made to ensure that the perspective used by the participants during the
21 experimental session was the same as the perspective identified by the VMIQ. Debriefs also
22 confirmed that the gymnasts were not switching from one perspective to another one within
23 the mental simulation and that they had followed the instructions for the content of imagery.

24 Second, information concerning the gymnasts' imagery process was also assessed.
25 This included the ease of image control, the imagery vividness, the use of other imagery

1 modalities (e.g., auditory, kinesthetic, olfactory), and any emotion associated with the
2 imagery process. The following questions were asked: Using the 5-point scale, was it easy or
3 difficult to generate mental images?; how vivid were your images?; what did you see as you
4 mentally simulated your vault routine?; do you think you simulated mentally your whole
5 vault, and each of its four stages, at the same rate as in reality, or was it quicker or slower?; as
6 you mentally simulated your vault routine, did you feel any sensations in your muscles?; did
7 you experience any emotional states?; did you speak to yourself during imagery and, if so,
8 what did you say?

9 *Procedure*

10 The procedure involved three stages: a pre-experimental questionnaire session; an
11 experimental session; and a post-experimental questionnaire session. This approach was based
12 upon a modified version of those employed by Decety and coworkers (e.g., Decety &
13 Jeannerod, 1996; Decety et al., 1989; Decety & Michel, 1989).

14 *Pre-experimental questionnaires session.* The VMIQ was completed by each gymnast
15 one week before the beginning of the experimental session. Eleven gymnasts were identified
16 as FPP users. They had a mean of 91.4 (SD = 15.99) for the FPP and a mean of 76.6 (SD =
17 18.64) for the TPP. A Wilcoxon test revealed a significant difference between the two
18 perspectives ($Z = 2.80, p < .006$). Six gymnasts were classified as TPP users. They obtained a
19 mean of 96.67 (SD = 12.82) for the TPP and a mean of 85.33 (SD = 17.90) for the FPP.
20 Again, a significant difference was found between the two perspectives ($Z = 2.02, p < .05$).

21 There was full agreement across all assessment methods. The preferential perspective
22 for each gymnast matched that identified through the VMIQ and was consistent with the
23 reports of the corresponding gymnast. One participant, with no dominant VMIQ perspective,
24 indicated switching between imagery perspectives when mentally rehearsing her vault. She
25 was removed from the study.

1 *Experimental session.* A between-subject design was employed in the present study.
2 The gymnasts were free to warm-up before starting the experimental session using their
3 normal routines. During this period of time, the experimental team did not control the way
4 participants prepared themselves to execute the actual vault and whether imagery was used.
5 The experimentation began after the gymnasts indicated that they were ready.

6 The gymnasts were asked to imagine performing the vault task in their preferred
7 imagery perspective. Imagery was performed in a standing position to address the postural
8 force concerns for temporal functional equivalence raised by Holmes and Collins (2001,
9 2002). Before imaging performing each vault exercise the following instructions were
10 provided to the gymnast, “I will ask you to imagine performing your vault with the
11 understanding that you are going to execute your vault in reality after having imagined it. You
12 should perform your imagery from your usual [internal/external] perspective.”

13 To consider the impact of timing congruence on the components of an action the vault
14 was divided into four stages:

15 Stage 1: The Run Phase. From the start of the run-up to the gymnast’s feet hitting the
16 springboard;

17 Stage 2: The First Flight Phase. From the end of Stage 1 to hands hitting the vault;

18 Stage 3: The Arm Support Phase. From the end of Stage 2 to the hands take-off from
19 the vault;

20 Stage 4: The Second Flight Phase. From the end of Stage 3 to the feet landing on the
21 mat.

22 The four stages of the Yurchenko vault were defined in this way because they were familiar
23 and meaningful to all the gymnasts and since they matched the typical learning stages of this
24 particular vault.

1 A finger tapping procedure was employed to allow the gymnasts to identify each stage
2 of the vault during the imagery process. Gymnasts were instructed to tap their fingers on their
3 thigh as they reached each stage transition and to make the onset of the tapping coincide with
4 the beginning of each stage of the imagined vault. Five taps were performed whilst they
5 imagined their vault and the four stages were identified for each participant. The motor
6 command to tap the leg could be seen as adding time to the mental stage. However, we would
7 suggest that the time to tap was perceived *not* to add extra time to the time required to
8 imagine the movement since participants decided consciously to prepare their finger tap
9 before actually doing it. This argument is in line with Libet (1985) who has shown that when
10 individuals executed freely voluntary acts (e.g., flexion of the wrist at any time they chose),
11 they became aware of their intention to move about 200ms before they actually moved. A
12 conscious anticipation seems to be present that would not significantly increase movement
13 times in the imagery conditions. Gymnasts were given five practice attempts to habituate to
14 the signaling system and reinforce that tapping at the start of each phase.

15 The second element of the experimental session required the gymnasts to physically
16 execute their vaults. The gymnasts performed an imaged execution of their vault followed by
17 a physical execution of the skill. This protocol maintained the reality of the training and
18 competition behavior. Indeed, Calmels, d'Arripe-Longueville, Fournier, and Soulard (2003)
19 have shown that just prior to the execution of their competitive routine, elite gymnasts
20 regularly simulate it mentally. Three trials were performed in each of the two conditions (i.e.,
21 imagined trial 1 followed by actual trial 1, imagined trial 2 followed by actual trial 2,
22 imagined trial 3 followed by actual trial 3) . The gymnasts were filmed under both mental and
23 actual conditions using a 25 Hz digital camcorder (Panasonic DS 15, mini DV). This
24 procedure allowed for the collection of total and stage times for the vault. The duration of
25 each stage was read from the frame timer of the camcorder.

1 *Post-experimental questionnaire session.* Full manipulation checks and debriefs were
2 employed after the experimental session. The imagery process was also monitored for each
3 gymnast.

4 Results

5 *Statistical Analysis*

6 ANOVAs were computed for the full Yurchenko vault time and for the separate times
7 for the four stages of the vault. For both ANOVAs, trial number was used as a factor in the
8 design, since mental durations could change across the three trials (see Decety, 1991). For
9 each ANOVA, the homogeneity of variance (homoscedasticity) was checked using the
10 Levene's test. Post-hoc comparisons were calculated using Tukey's HSD test.

11 All the variances showed homogeneity except trial 1 stage 3 under the physical
12 condition. Therefore, we used a more rigorous alpha level to correct the violation of
13 homogeneity (Tabachnick & Fidell, 2001).

14 *Full Yurchenko vault.* A $2 \times 3 \times 2$ (Perspective \times Trial \times Condition) ANOVA with
15 repeated measures was computed for the two within-subjects factors (trial and condition). No
16 interaction and no main effect was found for perspectives, for trials, or for conditions for the
17 full vault (see Table 1). The duration of the full vault exercise was consistent across the three
18 trials and in both perspectives, the time to imagine the full vault was not significantly
19 different to the time required to physically perform it (see Table 2, Figure 2).

20 *Four stages of the Yurchenko vault.* A $2 \times 4 \times 3 \times 2$ (Perspective \times Stage \times Trial \times
21 Condition) ANOVA with repeated measures was computed for the three within-subjects
22 factors (stage, trial, and condition). Only the significant effect(s) or interaction(s) have been
23 reported in this sub-section. Significant and non significant results have been displayed in
24 Table 3.

1 ANOVA revealed a significant main effect for the stage factor, $F(3,42) = 434.8731$, p
2 $< .000001$ (see Table 3). Tukey's HSD post-hoc tests showed that irrespective of perspective,
3 trial, and condition, duration of stage1 (3.569 sec) was greater than the duration of stages 2
4 (0.630 sec) ($p < .0002$), 3 (0.511 sec) ($p < .0002$), and 4 (0.960 sec) ($p < .0002$). Durations of
5 stages 2 and 3 were also less than the duration of stage 4 ($p < .007$, for stage 2; $p < .0003$, for
6 stage 3).

7 ANOVA revealed a significant stage-trial interaction, $F(6,84) = 2.7672$, $p < .02$ (see
8 Table 3). Regardless of perspective and condition, Tukey's HSD post-hoc tests indicated that
9 trial durations did not change across each stage except for stage 1. Trial 1 duration (3.504 sec)
10 was faster than trial 3 duration (3.621 sec) ($p < .03$).

11 ANOVA displayed a significant stage-condition interaction, $F(3,42) = 125.9179$, $p <$
12 $.000001$ (see Table 3). Tukey's HSD post-hoc tests showed that participants using both visual
13 perspectives mentally simulated stage 1 (run phase) at a faster rate ($p < .001$) and stages 2 and
14 3 (first flight phase and arm support phase) at a slower rate ($p < .0004$, for stage 2; $p < .0003$,
15 for stage 3) than they actually performed these stages during actual execution (see Figure 2
16 and Table 2).

17 *Post-experiment Questionnaire*

18 Participants' answers to the questionnaire established that they imagined performing
19 the task from the agreed perspective. Answers also confirmed that the gymnasts did not omit
20 any stages of the vault exercise. Participants also reported having experienced ease in
21 generating images and having formed clear and vivid images. During imagery, six
22 participants (three FPP and three TPP) expressed having experienced anxiety, three (one FPP
23 and two TPP) reported having felt kinesthetic sensations during the second and third stages of
24 the vault exercise, four (four FPP) declared having covertly verbalized (technical advice), and

1 four (two FPP and two TPP) mentioned having heard the sound of their feet when they ran,
2 hit the springboard and landed on the mat, and of their hands as they hit the vault.

3 Discussion

4 In this study, we aimed to investigate the temporal functional equivalence between
5 physical performance of a gymnastic vault and imagery of the same task from an internal
6 visual perspective and also from an external visual perspective. We also aimed to consider the
7 temporal organization of a complex task under imagined and actual execution from an internal
8 and external imagery perspective. The discussion is organized into three sections. The first
9 considers the chronometric comparison of actual and imaged full vault. The second section
10 discusses the chronometric comparison of actual and imaged vault stages and the third
11 considers the strengths and limitations of the study.

12 *Chronometric Comparison of Actual and Imaged Full Vault*

13 The findings of the present study showed that in an internal perspective imagery
14 situation, the time to image the full vault was not significantly different to the time required to
15 physically perform it. The finding provides support for previous behavioral studies (Decety &
16 Michel, 1989; Papaxanthis et al., 2002) that have shown that overt motor production and
17 motor imagery (i.e., imagery from a FPP) share similar brain mechanisms and activate similar
18 planning programs (Decety & Michel, 1989). It is possible that mental simulation and
19 execution of an action may be exposed to the same environmental and physiological
20 constraints (Papaxanthis et al., 2002) and governed by the same temporal rules (Maruff et al.,
21 1999). The absence of differences in mental and actual durations of the vault exercise could
22 also be due to the sensory and proprioceptive inputs related to movement performance. This
23 'stored', or regenerated information was presumably used during the image generation for
24 mental simulation (Decety, 1991; Kosslyn, 1994). It is, therefore, tempting to support the
25 claims of other researchers (Decety, 1991; Lewis & Miall, 2003) for the existence of an

1 internal clock for mental and actual executions. The finding that motor imagery and physical
2 execution of a skill may share a similar temporal driver should not be completely surprising
3 given the volume of research showing the activation of common brain areas for these two
4 processes (Grèzes & Decety, 2001).

5 The novelty of the present study was that imagery was also performed from an
6 external visual perspective. It was predicted that mental simulation of the full vault would be
7 faster than actual execution since the external visual perspective should involve less motor
8 processing as suggested by Mackay (1981; 1982). This was not the case. The time to imagine
9 the full vault from a third-person perspective was not significantly different to the time
10 required to physically perform it. We suggest that this finding may be explained by research
11 that has shown that the cortical motor system was active during both overt movement and
12 external imagery of a rotation task (e.g., Ganis, Keenan, Kosslyn, & Pascual-Leone, 2000;
13 Kosslyn, Digirolamo, Thompson, & Alpert, 1998). Imaging the full vault from an external
14 visual perspective required the gymnast to simulate mental rotations. Therefore, we suggest
15 that motor, in addition to visual, mechanisms may be active during the external visual
16 imagery condition and that this may explain the equality between actual and imagined actions.

17 For skilled performers, internal and external visual imagery displayed the same
18 temporal characteristics. This suggests that imagery conducted from a third-person
19 perspective may contain sufficient propositional information for these individuals to access
20 the representation in the same way as an internal perspective (Holmes & Collins, 2001, 2002).

21 *Chronometric Comparison of Actual and Imaged Vault Stages*

22 Trial was included as a factor in the design since Decety (1991) has showed that there
23 is the potential for temporal inconsistency across actual and imagined trials as a result of
24 feedback. This was not the case in this study and probably reflects the skill level of the
25 participants. In only one case (trial 1 duration was faster than trial 3 duration for the first stage

1 of the vault irrespective of perspective and condition) was there a difference. The condition
2 factor (mental and actual) and the perspective factor (internal and external) were
3 indistinguishable since they were averaged in the post-hoc comparisons. Only the stage factor
4 and trial factor could be discriminated.

5 The data also revealed that the temporal aspects of the vault components were not
6 consistent across imagery and actual conditions. Participants in both visual perspective
7 conditions imaged stage 1 (run phase) at a significantly faster rate than the physical condition,
8 stages 2 and 3 (first flight phase and arm support phase) at a significantly slower rate as the
9 physical condition and stage 4 (second flight phase) at the same speed as that which they
10 actually performed.

11 Stage 1 was the approach run to the springboard and its function was to provide
12 horizontal acceleration for the gymnast in preparation for the acrobatic movements. The
13 temporal discrepancy in stage 1 between the imagery and physical conditions for the
14 participants for both perspectives could be explained by Loomis, Da Silva, Fujita, and
15 Fukusima's (1992) foreshortening effect. In this regard, Stevens (2005) has recently suggested
16 that individuals minimize the distance in the imagined condition in the same way distances in
17 the depth plane are perceptually foreshortened. Therefore, this visual distortion reduces the
18 movement mental duration.

19 The duration of the imagined stages 2 and 3 (first flight phase and arm support phase)
20 was longer than the duration of the actual stages. These findings are consistent with those of
21 Orliaguet and Coello (1998) who argue for the absence of a temporal equivalence between
22 mental and actual movements where actual durations are around 250ms. They have suggested
23 that imagined and actual movements of this time scale do not share the same processing
24 systems. For fast movement, no possibility of 'closed-loop' regulation of the movement is
25 available to individuals as they actually execute it. During the mental simulation of

1 movements with short duration, participants focus more on the unfolding of the action that
2 might have evoked sensorial modes related to the motor act (Orliaguet & Coello, 1998). This
3 explanation is supported by the reports of the participants in the present study who declared
4 having heard their feet hit the springboard and their hands hit the vault, and having felt
5 kinesthetic sensation during stages 2 and 3 of their mental simulation. These reports of
6 conscious percepts during imagery are in contrast to the actual movement where no such
7 reports are made since the activity is performed in a less conscious state. These different
8 levels of processing may account directly for the temporal discrepancy between the imagined
9 and physical conditions during these stages.

10 A further explanation can be proposed to explain the longer mental duration of these
11 stages. Decety et al. (1989) and Jeannerod (1994) have shown that participants perceived an
12 increase in force as an increase in mental movement duration. This proposal supports the
13 gymnasts' reports. They explained that stages 2 and 3 required more effort and force than the
14 other stages because "you have to hit the springboard strongly and to push your arms to
15 perform successfully" (Gymnast X). The absence of these afferent forces during both imagery
16 conditions may have been perceived as additional time (Jeannerod, 1997).

17 The different results observed for the vault stages may also be explained by the
18 relationship between actual and mental duration which can be modified by the length of the
19 motor sequence. In the present study, the first stage, where imagined movement time was
20 faster than actual movement time, was also longer in duration than the other stages.
21 Conversely, stages 2 and 3, for which imagery times were slower than the actual times, were
22 very short in (actual) duration. Few studies have examined this point in the literature and
23 opinions vary as to its explanation. Minvielle-Moncla et al. (2003) have argued against the
24 length of the motor sequence having an influence on the difference between mental and actual
25 duration. In contrast, Le Her et al. (1997) showed that the time it took to image surfing on a

1 wave interacted with the actual duration of the wave; the longer the actual duration of a wave,
2 the shorter the mental duration of surfing on this wave. The relationship between actual and
3 simulated movement is clearly not simple. Reed (2002) has also shown that the relationship
4 can be altered by the participants' expertise and by the complexity of the skill. She showed
5 that, as skill complexity increases, imagery durations become longer and that, unlike novices
6 or experts, imagery durations for intermediate divers were slower than those of actual
7 durations. The extent that movement complexity and/or duration influenced imagery times in
8 the current study cannot be fully discussed and certainly warrants further investigation.

9 In a practical sense, it is also possible that stages 2 and 3 were extended in the imagery
10 conditions as a direct result of the emphasis placed on these elements by coaches at this level
11 of performance. The coach's reinforcement of these skills may direct attention to them during
12 imagery at the expense of the run up and landing. Therefore, whilst these aspects of the vault
13 may have shown temporal functional equivalence, the gymnasts' tacit knowledge of the
14 component importance results in a relatively greater amount of time being spent on it during
15 imagery.

16 *Strengths and Limitations of the Study*

17 This study investigated a series of complex motor skills performed by expert athletes.
18 These participants are not numerous and the findings may only be applicable to similarly
19 skilled groups. A within-subject comparison of imagery would have been a more effective
20 design, but to maintain ecological validity this was not possible. The gymnasts were unable to
21 employ the alternative visual perspective; in fact, they refused to mentally simulate their vault
22 exercise from their non-dominant perspective knowing that the aim was to perform the action
23 afterwards. A significantly modified pre-performance routine was considered unethical if
24 changing their imagery routines increased the risk of them being hurt. We also recognize that

1 the results could be linked equally to imagery perspective or imagery ability with the current
2 design. Future research should examine this issue further.

3 Despite these limitations, the study presents important findings. First, it has
4 investigated the functional equivalence concept of a complex, well-learned motor skill
5 performed by elite athletes in an ecologically-valid setting. Second, dividing the action into
6 stages has supplied a more refined appraisal of the temporal organization of a complex action
7 not previously considered. Third, examining the temporal functional equivalence during
8 imagery from an external visual perspective should promote greater use of this perspective for
9 experienced performers as its temporal aspects were found to be the same as those of the
10 internal perspective. Finally, the debrief interviews highlighted that there may be a number of
11 additional imagery characteristics that may have had an influence on imagined time. These
12 include concurrent kinesthesia which has been shown to influence image time. However, the
13 reports of kinesthesia were consistent across visual perspective and therefore remain to be
14 examined more fully in future studies.

15 Conclusion

16 At the simplest level, the study would seem to provide partial support for functional
17 equivalence considered through a timing paradigm. The findings revealed that the duration of
18 an imagined motor task was not significantly different from the time required to actually
19 perform it irrespective of the visual perspective employed. However, when the motor task was
20 considered more fully in its component stages, correspondence between imagined and actual
21 times was lost. Three of the four stages of the task exhibited absolute temporal discrepancies
22 between the imagery and physical conditions. These results cannot be discussed in the context
23 of any previous research because, to our knowledge, no research has fully addressed this
24 relationship. These results suggest the cautious interpretation of previous research in this area
25 since the use of total time as a measure in a multi-component task may not be appropriate and

1 may conceal some important features of the task. Further understanding the disparity between
2 imagined and actual times and exploring the multifarious influences on imagined time
3 certainly warrant further investigation.

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3

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1 Table 1

2 *Summary of the 2 x 3 x 2 (Perspective x Trial x Condition) ANOVA*

3

	F	p
Perspective	1.475	0.24
Trial	0.417	0.66
Condition	2.631	0.13
Perspective x Trial	1.960	0.16
Perspective x Condition	0.092	0.77
Trial x Condition	0.201	0.82
Perspective x Trial x Condition	1.214	0.31

4

1 Table 2

2 *Means and Standard Deviations of Imagined and Actual Durations (in seconds)*

3

	Full vault		Stage 1		Stage 2		Stage 3		Stage 4	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Participants imaging from a first-person perspective										
Imagined trial 1	4.98	1.92	2.21	0.71	0.89	0.49	0.78	0.52	1.11	0.52
Imagined trial 2	4.78	2.06	2.10	0.77	0.92	0.51	0.75	0.57	1.01	0.51
Imagined trial 3	4.96	2.07	2.24	0.83	0.89	0.50	0.78	0.58	1.05	0.50
Imagined trials	4.91	1.95	2.18	0.75	0.90	0.49	0.77	0.54	1.05	0.49
Actual trial 1	5.80	0.46	4.43	0.46	0.31	0.03	0.22	0.05	0.84	0.09
Actual trial 2	5.81	0.39	4.46	0.43	0.32	0.02	0.19	0.03	0.85	0.09
Actual trial 3	5.92	0.36	4.54	0.38	0.32	0.04	0.20	0.03	0.86	0.07
Actual trials	5.84	0.40	4.48	0.41	0.31	0.03	0.20	0.04	0.85	0.08
Participants imaging from a third-person perspective										
Imagined trial 1	5.50	1.60	2.49	1.09	1.04	0.45	0.89	0.46	1.08	0.49
Imagined trial 2	5.84	1.45	2.82	1.20	1.04	0.46	0.86	0.51	1.12	0.51
Imagined trial 3	5.60	1.67	2.77	1.04	0.85	0.37	0.85	0.45	1.13	0.44
Imagined trials	5.65	1.49	2.69	1.05	0.98	0.42	0.87	0.45	1.11	0.45
Imagined trial 1	6.24	0.48	4.89	0.43	0.33	0.04	0.20	0.01	0.82	0.12
Actual trial 2	6.30	0.43	4.95	0.42	0.34	0.04	0.21	0.02	0.80	0.10
Actual trial 3	6.32	0.36	4.93	0.36	0.33	0.02	0.20	0.02	0.87	0.06
Actual trials	6.29	0.40	4.92	0.38	0.33	0.03	0.20	0.02	0.83	0.09

4

5 *Note.* Stage 1: the run phase; stage 2: the first flight phase; stage 3: the arm support phase;
 6 stage 4: the second flight phase.

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1 Table 3

2 *Summary of the 2 x 4 x 3 x 2 (Perspective x Stage x Trial x Condition) ANOVA*

3

	F	p
Perspective	1.475	0.24
Stage	434.873	***
Trial	0.416	0.66
Condition	2.630	0.13
Perspective x Stage	2.512	0.07
Perspective x Trial	1.960	0.16
Stage x Trial	2.767	*
Perspective x Condition	0.092	0.77
Stage x Condition	125.918	***
Trial x Condition	0.200	0.82
Perspective x Stage x Trial	1.848	0.10
Perspective x Stage x Condition	0.004	0.99
Perspective x Trial x Condition	1.213	0.31
Stage x Trial x Condition	0.750	0.61
Perspective x Stage x Trial x Condition	1.534	0.18

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5 *** $p < .000001$, * $p < .02$

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Figure Captions

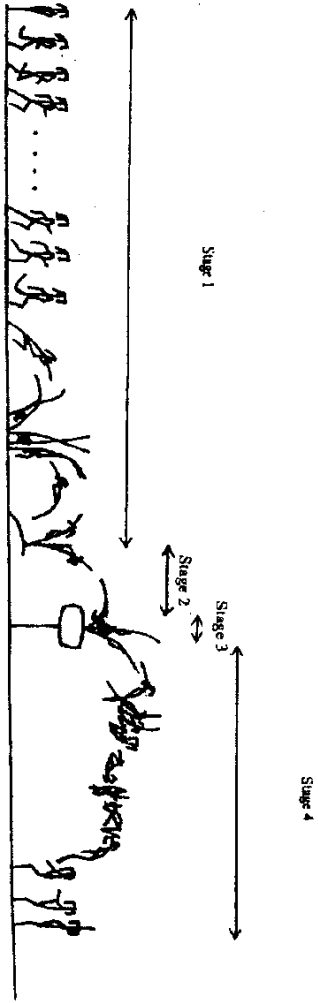
3 *Figure 1.* The Yurchenko vault and its four stages

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5 *Figure 2.* Mean times (sec) for the 16 gymnasts for the imagined and physical actions and the
6 four stages irrespective of visual perspective

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