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# Effects of unintentional coordination on attentional load

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## Abstract

The goal of this study was to evaluate the impact of unintentional (spontaneous) coordination on high attentional visual load. More precisely, we wondered whether such coordination could free up some attentional resources and help improve performance in other more demanding attentional tasks. An experiment was performed in which participant attentional allocation was challenged by performing three tasks simultaneously while simultaneously being induced to unintentional entrain to an environmental rhythm. The first task was an interception task associated with a Stroop test to increase their attentional load. The second task was a reaction time test to alarms in different modalities (auditory, visual and bimodal) which was used to assess participant attentional load. The third task was a motor task in which participants were asked to swing their legs at a preferred frequency. The interface background brightness intensity was either synchronized in real time using a bidirectional coupling to participant leg movement or the background brightness was not changing at all. Our results on the reaction time task demonstrated that participants exhibited better reaction times for alarms in the bimodal condition than in the auditory condition and lastly for the visual condition. Also, participants exhibited a lower reaction time to

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alarms when the background brightness was synchronizing with their leg regardless the alarm modality. Overall, our study suggests a beneficial effect of unintentional environmental coordination on attentional resource allocation and highlights the importance of bidirectionality in interaction.

*Keywords:* attentional load, unintentional coordination, human-machine interaction

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## 1. Introduction

Human ability to coordinate his/her motor behavior with external stimulus is essential and necessary in daily life. Humans can coordinate and synchronize with both non-social sensory signal such as a perceived object  
5 moving on a screen (e.g., Schmidt et al. (2007)) or social sensory signal induced by another human (e.g., Schmidt & Richardson (2008)). An alteration of this capacity can be very disabling when interacting with the environment in the broad sense or more specifically during social interactions. It can even be considered as a sign of a social deficit. Human-environment coordina-  
10 tion or interpersonal coordination deficiency can have their origins in specific pathologies. For instance, it can come from motor control problems, as in the case of Parkinson's (Cock et al. (2020)) or Alzheimer's diseases (Moreau et al. (2016)), or attentional mechanism deficits, as found in schizophrenia patients (Varlet et al. (2012)) and autistic people (Fischer et al. (2020)). Both motor  
15 control and attentional mechanisms are essential components in producing correctly timed motor behaviors coordinated with the sensory signals.

Obviously, for synchronization to occur regardless of whether it is social or non-social, the stimulus to be coordinated with must be perceivable. (Richardson & Kerry L Marsh (2005)): There must be information available  
20 about the stimulus via the visual (Schmidt et al. (2007)), auditory (Shockley et al. (2007)) or tactile modalities (Lenay (2010)). But the information must not only be available, it must be picked up. For such information pickup to occur, one needs to dedicate enough attentional resources toward the stimulus in interaction with. Indeed, how can we visually observe a moving target,  
25 or listen to a metronome without a minimum of attention focused on these stimuli? Attentional mechanism during human-environment or interpersonal coordination is consequently crucial and represent the main interest of the present study described in this article.

Conceptual and methodological frameworks have already been established

30 for the study of information pick up and attention during interpersonal co-  
ordination. For instance, in terms of visual information, several articles have  
shown that some visual cues are better suited to establish interpersonal co-  
ordination based on the amount of attention participants can display. For  
example, participants exhibited more stable coordination with a stimulus  
35 when they tracked it with their eyes (Schmidt et al. (2007)). *Hajnal et al.*  
found that the amount and location of available visual information influence  
visual attention, hence, the stability of the observed synchronization (Haj-  
nal et al. (2012)). Moreover, a study conducted by *Varlet et al.* found that  
synchronization stability was significantly improved for a continuous visual  
40 signal compared to discrete ones (Varlet et al. (2012)). In this experiment,  
the authors compared two visual conditions, one using a light flash and an-  
other using a fading light. The results showed better stability for the fading  
condition. In fact, the more information the perceiver gets the greater is  
the coupling and the better is the coordination. In other words, the more  
45 information there is the more attention can be used to the performance of  
the task.

*Temprado and Laurent* have studied the association of a bi-manual coordi-  
nation task between two humans with a discrete reaction time (RT) task  
(Temprado & Laurent (2004)). In this research, RT was used as a measure  
50 of the attentional load which is the amount attentional resource was needed  
to follow the instructions. Authors showed that reaction times were higher  
when participants were instructed to give priority to the coordination task  
than during shared-attention condition. Moreover, authors compared the  
results for two types of pattern coordination: in-phase and in anti-phase.  
55 In-phase pattern is known to be a more stable pattern than the anti-phase  
one (Schmidt & Richardson (2008)). Results demonstrated that participants  
had lower RT during the in-phase condition (the more stable condition) than  
anti-phase one. The authors also found that RT also increased in dual-task  
conditions compared to the single-task condition for both pattern of coordi-  
60 nation. Taken together, these results showed that performing an intentional  
coordinated movement pattern has an attentional cost which depends on the  
stability of the coordination pattern. The more stable is the pattern, the  
less it is demanding in term of cognitive resources. In contrast, several stud-  
ies have shown that when our attention is not focused on our movement,  
65 many coordinated movement patterns from sequential finger tapping to well-  
practiced sport moves can be performed automatically by individuals with  
almost no conscious guidance (Zhang et al. (2019); Abernethy et al. (2007)).

Indeed, attention can modulate automatic movements (Zhang et al. (2019)) and even disrupts well-practiced ones (Wulf et al. (2001, 2002)) whereas, 70 movements performed without attentional focus, allow us to distribute our limited attentional resources to other important tasks.

Nevertheless, all these previous studies have analyzed attentional mechanisms only in the case of intentionally coordinated and unidirectional movement patterns. Unintentional and bi-directional coordination have almost 75 never been taken into account in the context of attention load. However, bidirectionality and unintentionally are key characteristics of interpersonal coordination.

Interpersonal and human-environment coordination share similar characteristics as they are driven by the same basic organizational principles 80 (Schmidt & Richardson (2008)). The same oscillatory dynamical coordination patterns and stabilities are observed when interacting with a human or a non-social stimulus. For instance, the two preferred and differentially stable modes of in-phase and antiphase (Schmidt et al. (2007)) and an abrupt transition when increasing the frequency of the limb (Wimmers et al. (1992)) 85 occur for intentional interpersonal coordination tasks. Moreover, the same dynamical coupled oscillatory equations have been used to model those patterns. The difference between social and non-social stimuli is mostly based on the unidirectional and bidirectional aspect of the interaction. When interacting with someone, usually (but not all the time), the two individuals 90 influence each other. One person's action triggers the other one's action and vice versa. The coupling of the individuals is bidirectional. However, when a human is synchronized with the environment, the human adapts to the environment. The coupling with the environment is unidirectional. The coupling and the coordination performance is stronger in a bidirectional coupling than 95 in unidirectional one (Kelso et al. (2014)) which may have a significant effect on attentional mechanisms needed to sustain it. Nonetheless, recent work has demonstrated that if an artificial social agent adapts to a human actor's dynamics (establishing a bi-directional coordination) similar motor behavior characteristics are found during that Human-Robot interaction compared to 100 human-human interactions (Hasnain et al. (2013); Ansermin et al. (2017); Aubin et al. (2021)). Nevertheless, attentional mechanisms involved in interpersonal coordination have not been analyzed.

To do so, the unintentional aspect of natural interpersonal coordination must also be taken into account. Several articles have studied how humans 105 both intentionally and unintentionally synchronize with a non-social sen-

sory (e.g., Schmidt et al. (2007)) or with another human (e.g., Schmidt & Richardson (2008)). Intentional synchronization occurs when humans have the conscious goal to coordinate their movements with a coactor to perform a task such as moving furniture, playing music. Conversely, unintentional synchronization (also called spontaneous synchronization) occurs when individuals synchronize their movements with another person's but do not have an explicit, conscious goal to do so. For instance, unintentional synchronization occurs when a person synchronizes his/her steps when walking side by side with a partner without being aware of it. Such spontaneous (unintentional) coordination may appear between an individual and an environmental stimulus any time that there is information available about an environmental rhythm regardless the sensorial modality involved. It can happen in a very simple way with auditory (e.g. music, discrete rhythmic tones) (Repp (2006); Repp & Penel (2004)) or visual stimuli (e.g. moving visual environment, moving/flashing light) (Dijkstra et al. (1994); Buekers et al. (2000)), but also in social interactions when talking, walking or applauding with another person (Shockley et al. (2003); van Ulzen et al. (2008); Néda et al. (2000)). This unintentional coordination phenomenon has been the subject of numerous studies of interpersonal coordination where its presence and generality have been demonstrated many times (Schmidt & Richardson (2008)). for example, it has been found that, in addition to being non-conscious and spontaneous, it is apparently an unavoidable phenomenon (Issartel et al. (2007)). *Schmidt et al.* revealed that the same principles appear when humans visually coordinated unintentionally with a non-social stimulus as a moving dot on a screen (Schmidt et al. (2007)). Unlike intentional coordination, unintentional coordination is less stable and often intermittent (Schmidt & Richardson (2008)) as it is not a "priority-task" in the sense that it is not something we consciously try to maximize. However, we know that there are conditions which favor its emergence and which increase its stability. Indeed, the strength of unintentional rhythmic entrainment has been found in the past to be modulated by the difference between the preferred frequencies of agents' movements (Lopresti-Goodman et al. (2008)). The closer preferred frequencies are to each other, the more stability is obtained and greater is the coordination. In addition, one observes less stable synchrony for unintentional tasks and a degree of metastability that depends on the tempo difference between the two movements (Schmidt et al. (2007)). This latter outcome verifies that there is only a small range of frequency differences for which unintentional coordination emerges with a rhythmical environment (Strogatz (1994)). Many

of the above studies have indicated that unintentional synchronization with  
145 a non-social stimulus is as stable as synchronization with another human.  
However, these findings have not evaluated what happen when an actor has  
to handle the performance of multiple tasks simultaneously or how humans  
cope with additional tasks in presence of unintentional synchronization when  
his/her attention is divided in multiple directions. Does the performance of  
150 unintentional synchronization with a stimulus allow other task to be per-  
formed more easily? How is the allocation of attentional resources impacted  
by the performance of unintentional synchronization?

By its non-conscious nature, unintentional coordination can perhaps be  
seen as a background mechanism handle by the central nervous system (CNS)  
155 while performing a voluntary task as for example: two persons talking to each  
other while walking and unconsciously synchronizing their steps together. We  
can therefore ask a general question: how does the CNS handle both tasks  
simultaneously in terms of allocation of attentional resources in spontaneous  
synchronization situations? And more specifically, what is the attentional  
160 cost of such a background task during unintentional coordination? To our  
knowledge, no study has yet explored this issue. The goal of this present  
research study is therefore to evaluate the impact of unintentional coordina-  
tion induced by a rhythmic visual stimulus on the allocation of attentional  
resources when there is a high attentional visual load. We will use a high  
165 attentional load for two main reasons. First, because overloading a system  
is one of the best way to understand how different processes compete and  
function together (Pashler (1994)) and we want to enhance the chances to  
observed the impact of unintentional coordination on attention resources.  
Second, we want to be consistent with past research that has used multi-task  
170 paradigms to investigate the attentional demand of a motor task (Abernethy  
(1988)). For example, unintentional coordination appears in situations where  
people are not focused on their movements but on others tasks that are per-  
formed in parallel as in the experiment conducted by (Schmidt et al. (2007)).  
In this experiment, participants were asked, during the first condition, to read  
175 a letter appearing on a square which was moving at a certain frequency while  
swinging a hand-held pendulum at their preferred frequency (tracking con-  
dition). In the second condition, the moving square was still present but the  
written letter was on a fixed square just above the moving one (no tracking  
condition). The authors showed that the entrainment effect (present in unin-  
180 tentional situations) occurred for both conditions, tracking and no tracking,  
however, entrainment was stronger when the stimulus was visually tracked

and even stronger when the stimulus period was equal to a participant's preferred frequency. These results using an unintentional synchronization task were in line with those found in studies which have explored the impact of visual stimulus on intentional coordination. Indeed, many of studies have found that spatial information in addition to temporal information, as for example a stimulus oscillating horizontally, improves synchronization (Buekers et al. (2000); Armstrong et al. (2013)). Therefore, using a multi-task paradigm was the classical methodology to observe attentional demand as well as unintentional coordination.

In summary, since unintentional coordination can be reached without attentional focus (even if focal vision leads to higher non-intentional coordination compared to peripheral vision Richardson et al. (2007)), we can imagine that such coordination frees up some of the attentional resources, in the same way that automation of movements does. It would mean that, unintentional coordination should help us to improve our performance in another task more demanding in term of attention. This is the question we address in this paper. The question was therefore as follow: In a context where the level of attentional load on visual attention is high and where unintentional coordination is present, does unintentional coordination yield a rhythm that helps the participant to liberate a part of the attention load for other tasks or, does it require an amount of attention resources having a detrimental impact on other tasks performance?

In order to address this question, we created a video-game like interface where participants had to simultaneously perform different tasks: an interception task, a reaction time test eliciting different sensory modality alarms and an unintentional coordination task at participants' preferred frequency. Altogether, performing these three tasks created a shared-attention challenge. We hoped that such an attention load would reveal effect of unintentional coordination on attention allocation processes. We hypothesize that unintentional synchronization allows some attentional resources to be released in order to improve the performance of the other high demanding tasks.

## 2. Methods

### 2.1. Participants

The experiment involved 20 participants, 11 men and 9 women. The mean age of the participants was 24 years (standard deviation +/-4). Among



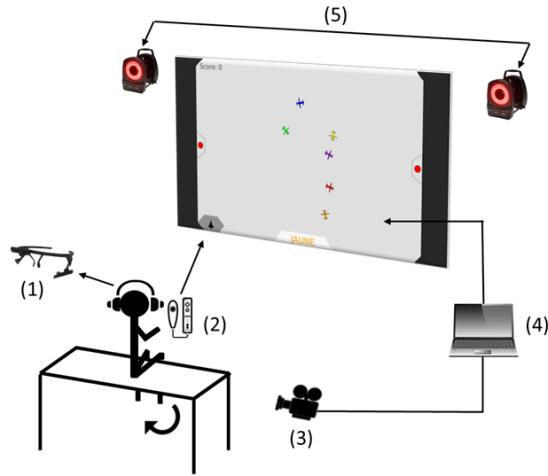


Figure 1: Experimental setup - (1) Eye-tracker, (2) Joy-stick, (3) Camera filming legs' motion to compute in real time the optical flow in (4) to allow background's brightness synchronization, (5) Motion capture

them, 13 were right-handed and 7 left-handed. All subjects gave their written informed consent. All procedures were in accordance with the 1964 Helsinki  
 220 declaration, and were approved by the EuroMov Institutional Review Board (IRB # 2102).

## 2.2. Procedure & Task

### 2.2.1. Procedure

Participants were seated on a table positioned at a fixed distance from  
 225 a screen where the video task was projected. The table was high enough so that their legs could swing freely **in the anterior-posterior direction**. Next to the table, a camera was positioned so that it could record legs movements. Participants were equipped with an eye-tracker and white reflecting markers were placed on the top of their knees and feet so that their motions could be  
 230 recorded thanks to a motion capture system (Vicon). Once the eye-tracker was calibrated, participants were asked to not move their head as the system needed to stay fix to retrieve accurate gaze positions. To be able to interact with the game, participants wore earphones and held in their hands a wireless remote including a joystick and a button (see Figure 1).

235 2.2.2. *The game design*

We wanted to be able to observe the impact of performing an unintentional coordination on high attentional load. For that purpose, our game design had to fulfill three intended purposes, namely **requiring a high attentional level**, being able to a certain extent to **characterize cognitive**  
240 **load** and **allowing non-intentional coordination** to appear at the same time. To do so, we have created a game consisting in three different tasks, each of them having a distinct role to meet these objectives.

The **first task** had one purpose, stimulate *selective* and *sustained* attention with a monitoring task. With their joystick, participants controlled  
245 a small airplane with which they had to reach targets represented by other small airplanes with different colors moving randomly on the screen. Each target reached was equal to one point and the score was displayed on top of the screen. To know which target to reach, participants had to resolve a Stroop test located on the bottom of the screen: The subject had to intercept  
250 the airplane possessing the color of text that a color word was written in. For example, the word 'purple' was in blue text. In this example, the color to follow is not the one written (here purple) but the one of the text, here, blue (see Figure 2). This test is especially useful to challenge *selective* attention. The test was updated every 8 seconds leaving only little time to accurately  
255 intercept the target.

The **second task** was a reaction time test, used to estimate cognitive load of participants (Luce (1991)): a high reaction time corresponding to the highest cognitive load and a low one corresponding to the lowest cognitive load. While performing the monitoring task, participants were asked to re-  
260 spond as fast as possible to an alarm. This alarm appeared only once, at a random time and lasted as long as participants didn't respond to it. To respond to the alarm, they just had to press a button located on the remote. Moreover, the alarm could be of different modality: **visual, auditory or both**. In any case, participants were informed for each trial of the modality.  
265 When the modality was visual, the alarm was represented by two oscillating red points (oscillating in term of size) appearing at each side of the screen (see Figure 2). When the modality was auditory, a sound at 600hz oscillating in term of volume could be heard in their earphones. When the modality was bimodal, visual and auditory alarms were activated.

270 The **third task** was that the participants swing legs at their preferred frequency during the entire trial. Their preferred frequency is the frequency

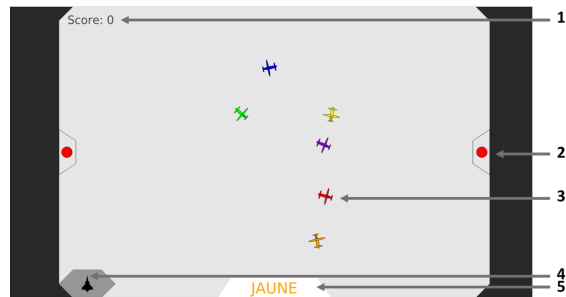


Figure 2: (1) Score, (2) Visual alarms, (3) Targets, (4) Participant’s plane, (5) Test of Stroop

which was the most comfortable and that did not require much awareness. The goal of this task was to fulfill the third objective of the game: Allow non-intentional coordination to appear. To create the unintentional environmental coordination, we designed the game’s background to oscillating in intensity at the frequency of oscillation of participants’ legs. Participants were not informed about this synchronization and the cover story was that the camera filming their legs was only here to check that they never stop swinging. With the background synchronizing, we enhanced the natural and unavoidable rhythmical entrainment that appears when both entities have very closed frequencies (Issartel et al. (2007)). In order to achieve this real-time synchronization, we used a model developed by *Hasnain et al.* that we described in the *Interface Synchronization* section. Furthermore, to be able to evaluate the impact of non-intentional coordination, we also created a control condition where the game’s background was not oscillating (see Conditions section below).

. Participants were told that, to perform all these tasks, they needed to achieve the best score on the interception task while having the best reaction times and never stopping the swinging of their legs. Those three tasks were able to challenge: *selective attention* with the test of Stroop, *divided attention* by the multi-tasking nature of the game and *sustained attention* by lasting 45 seconds (one trial) during which attention couldn’t be released to succeed. Moreover, reaction times measurements were able to estimate participants’ cognitive load.

295 *2.2.3. Materials*

We used eight infrared cameras (Nexus MX13 Vicon System ©, 100 Hz) tracking 4 reflective markers placed on participant’s legs (2 on both knees and 2 on both feet) in order to accurately assess legs motion. The eye-tracker was from Pupil Labs and the remote we have used was the nunchuk from  
300 Nintendo Wii.

*2.3. Conditions*

The conditions were designed to highlight the impact of unintentional coordination on the cognitive load for different modalities of the alarm. To do so, we needed a condition for each modality where non-intentional coordination could emerge and a control condition (with no appearance of leg  
305 entrainment). Consequently, there were 6 conditions, 3 conditions for alarm modality for each of the 2 conditions for the background oscillation (no movement VS synchronization).

**1. Background synchronizing:**

- 310 (a) The alarm’s modality is auditory  
(b) The alarm’s modality is visual  
(c) The alarm’s modality is bimodal

**2. Fixed background (control condition):**

- 315 (a) The alarm’s modality is auditory  
(b) The alarm’s modality is visual  
(c) The alarm’s modality is bimodal

For each condition, participants had 3 trials.

*2.4. Interface Synchronization*

In order to allow the background’s brightness to synchronize in real-time  
320 with participants’ movements, we have used a model developed by Hasnain et al. (2013). It consisted in a neural oscillator composed of two neurons  $N_1$  and  $N_2$  inhibiting each other proportionally to the variable  $\beta$ . The oscillating frequency was a function of the variables  $\alpha_1$ ,  $\alpha_2$  and  $\beta$ :

$$N_1(t + 1) = N_1(t) - \beta N_2(t) + \alpha_1 \tag{1}$$

$$N_2(t + 1) = N_1(t) + \beta N_2(t) + \alpha_2 \tag{2}$$

325

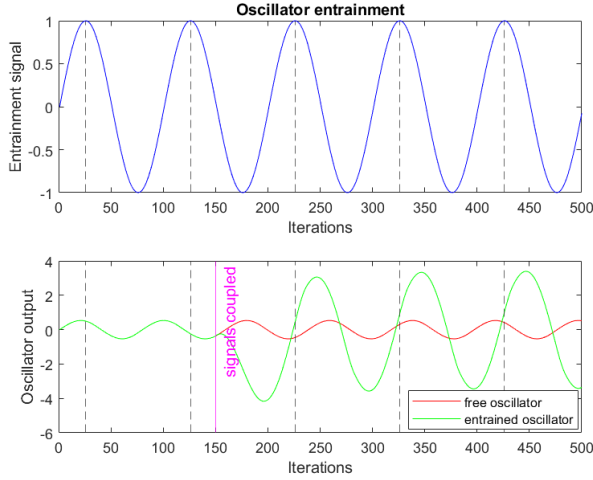


Figure 3: Oscillator entrainment: The Oscillator was entrained starting from iteration 150 (vertical line) by a sinus signal with a coupling factor of 0.2

The camera located next to participants' legs recorded their swinging movement **from their right-hand side**. Then, the optical flow of the leg movement was computed and integrated to obtain a quantity of motion (energy). **Due to the location of the camera on participants' right hand side, the quantity of motion's amplitude increased when legs were going to the right (anterior direction for participants) and decreased when legs were going to the left (posterior direction for participants)**. This signal noted  $f'$  was then multiplied by a coupling factor  $cp$  and added to the oscillator  $N_1$ :

$$N_1(t + 1) = N_1(t) - \beta N_2(t) + \alpha_1 + cp.f'(t) \quad (3)$$

Depending on the coupling factor  $cp$ , the output of the neuron  $N_1$  was synchronized with  $f'$  which was called entrainment signal and represented the participant's quantity of motion over time. The higher the coupling factor, the stronger the synchronization (see example Figure 3). For more details on the neural model we invite the reader to refer to Hasnain et al. (2013).

In this current experiment, the neural oscillator parameters were  $\beta = 0.2$ ,  $\alpha_1 = \alpha_2 = 0.1$ , the coupling factor  $cp$  was set to 0.6. Oscillator's output of the neuron  $N_1$  which was between -1 and 1, was sent to the game interface to set up the brightness in way that it stayed in a range of light to medium gray (gray level thresholds: 150 to 250)(Figure 4).

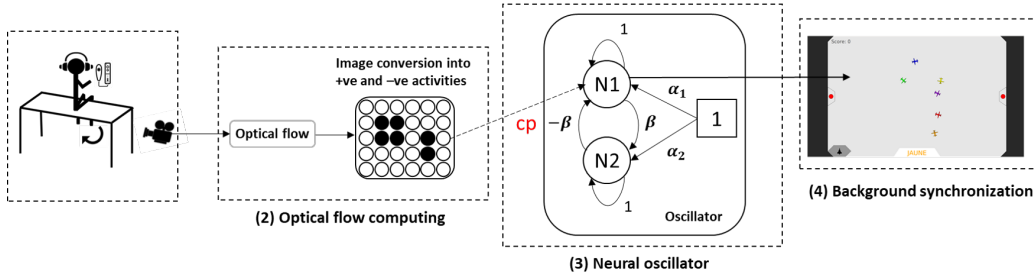


Figure 4: Model of control

### 2.5. Data analysis

345 We have studied four dependent variables: reaction time, score, visual fixation and leg frequency of oscillation and its stability. Reaction times were retrieved with the joystick and used as markers of cognitive load. Scores (number of targets intercepted) were recorded for every trial to determine if there was any correlation with reaction time. Visual fixation and leg frequency were calculated as detailed below. We also need to evaluate the quality of the synchronization between participants and the interface background.

#### 2.5.1. Interface synchronization

355 We used two measures to check on the coordination between background's brightness and participants. The first is the difference between leg period and background period (DP) to assess the degree of synchronization between the two agents (equation (4)). Each period was computed using the mean of all of the cycle periods contained in the signal. Because the period difference doesn't provide information about relative phasing of the two signals, we also computed an index of synchrony (IS) between leg signal  $S1$  and background signal  $S2$  checking for phase differences. IS is computed as in Equation (5) and is between 0 and 1 (0: no synchronization and 1: perfect synchronization).

$$DP = |T_{human} - T_{background}| \quad (4)$$

365 With  $T_{human}$  and  $T_{background}$  respectively human and background signal's period.

$$IS = \frac{\sum_{i=1}^N \cos(\theta_h^{S1}(i)) - \theta_h^{S2}(i)}{N} + \frac{\sum_{i=1}^N \sin(\theta_h^{S1}(i)) - \theta_h^{S2}(i)}{N} \quad (5)$$

$\theta_h^{S1}$  and  $\theta_h^{S2}$  are respectively the Hilbert transform angles of the signals  $S1$  and  $S2$  after centering them relative to their mean value.  $N$  is the number of samples.

### 2.5.2. Visual Fixation

370 The eye-tracker data was a complementary variable to assess the reaction times outcomes. Indeed, participant eye fixations can give an idea of where the visual attention is shifted toward.

To do so, we discretized the interface display into 5 areas: two areas for alarms, one central area including airplane zone and Stroop label, one  
375 area for the score and one for the controlled airplane base (see Figure 5). To determine which zone a given visual fixation belonged, we computed the Euclidean distance of the fixation point to every area's center and chose the smallest. Then, we have checked number of fixations and time spent in alarm area for each of the 6 conditions.

380 To represent alarms areas, we calculated all the fixations belonging respectively to the left and the right alarm (every subject and every trial) for conditions with visual alarm. Then, we kept fixations which appeared in the window of time between alarm's appearance and reaction time. We have computed the standard deviation for fixations' x and y coordinates relatively  
385 to the center of either the left alarm for fixations on the left part of the interface or the right alarm for fixations on the right part of the interface. Next, we determined the maximum standard deviation in x and y between the left and the right alarm, multiplied it by two to ensure gathering the entire distribution and then drew two ellipses representing alarm areas.

390 The score and the base zone were calculated using the same method as the one used for alarms but this time using all fixations from all conditions, with no delimitation in time and of course relatively to their zone's center. Lastly, the central area was delineated by a circle that represented the area where planes were moving.

### 395 2.5.3. Legs' frequency and stability

The oscillating leg movement signal was retrieved through the motion capture and filtered using a Butterworth filter with a 0.04Hz cut-off frequency.



Figure 5: Discretization of the interface in 5 areas: (1) planes zone/Stroop label, (2)/(3) alarms, (4) score and (5) plane’s base zone

We then computed frequency and frequency standard deviation to describe the stability of participants’ movements across all conditions. Frequency was determined using the mean of all of the cycle periods contained in the signal.

### 2.6. Statistics

We used 3 Modality (auditory, visual, bimodal) x 2 Background (synchronizing or not) mixed factor ANOVAs to compare the effect of alarm modality and background synchronization on reaction times. To do so, we performed it on the logarithm transformation of reaction times so that data could be normally distributed and respect ANOVA’s assumptions. For eye-tracker and motion capture data, normality was not obtained even with a logarithm transformation so we used Friedman non-parametric repeated-measure test. Sphericity tests were made for all variables. We used a p-value threshold of 0.05 for significance. We used a Pearson correlation coefficient to check if there was any correlation between reaction time and score/leg’s frequency/leg’s frequency stability. Statistical analysis were performed with Jamovi software (The jamovi project (2020), jamovi (Version 1.1.9) for Windows).

## 3. Results

### 3.1. Interface synchronization

For all conditions combined, the difference between human period and background period (DP) and the index of synchronization (SI) were  $0.010 \pm 0.017$  and  $0.995 \pm 0.007$ , respectively. These results confirm that the synchronization has been achieved.



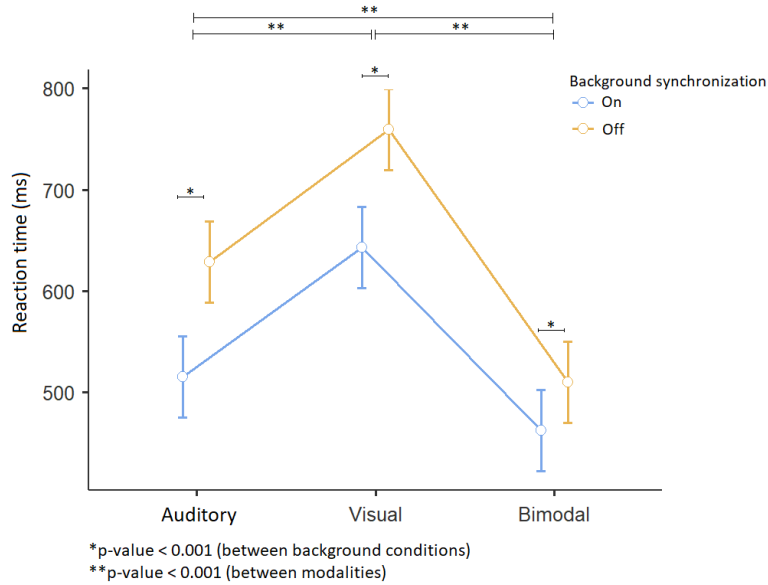


Figure 6: Reaction time against modality/background synchronization for each condition detailed

### 3.2. Reaction time

The 3 x 2 ANOVA showed that there was an effect of the modality ( $F(2, 38) = 18.22, p_{modality} < 0.001$ ) and background ( $F(1, 19) = 17.98, p_{background} < 0.001$ ) on reaction time but no significant interaction ( $F(2, 38) = 0.43, p_{modality*background} = 0.64$ ) (see Figure 6). Indeed, reaction time was much better (i.e., lowest time) when the background was synchronizing than when it was not moving. Moreover, reaction time was also lowest when modality was bimodal, followed by auditory while the visual modality produced the highest reaction time. We also examined whether there might be a correlation between reaction times and scores. The correlation of reaction times and scores was not significant (Pearson’s coefficient  $r(340) = -0.04, p = 0.45$ ).

### 3.3. Visual Fixation

For all modalities combined, we evaluated the number of fixations and the time spent in alarm’s defined areas in the two conditions of background

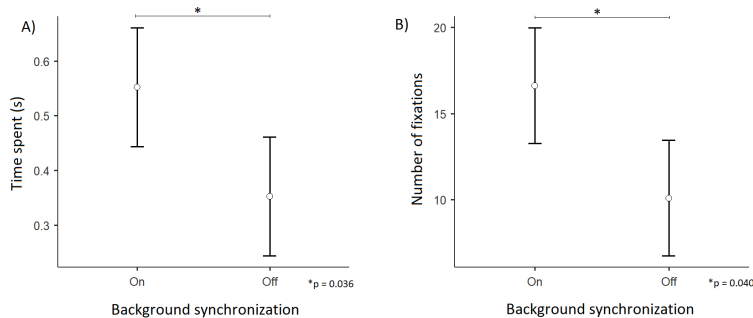


Figure 7: (A) Time spent in alarm’s defined areas against background synchronization (B) Number of fixations in alarm’s defined areas against background synchronization, all modalities combined

435 (synchronized and not synchronized)<sup>1</sup>. A Friedman non parametric repeated  
 measure test showed that background synchronization had an impact on  
 the number of fixations ( $\chi^2 = 11.6$ ,  $p = 0.04$ ) and on the time spent in  
 alarm’s defined areas ( $\chi^2 = 11.9$ ,  $p = 0.036$ ) (see Figure 7). Indeed, when  
 the background brightness was synchronizing, there were more fixation and  
 440 a greater time was spent in alarm’s defined areas. Then, we performed a  
 Durbin-Conover test to do pairwise comparisons in order to see for which  
 modality the impact of background synchronization had the greater effect.  
 For the number of fixations, the test revealed an effect for the visual condition  
 only ( $p_{visual} = 0.038$ ,  $p_{auditory} = 0.542$ ,  $p_{bimodal} = 0.406$ ). We found a similar  
 445 result for the time spent in alarm area ( $p_{visual} = 0.037$ ,  $p_{auditory} = 0.403$ ,  
 $p_{bimodal} = 0.290$ ).

### 3.4. Legs’ frequency and stability

To evaluate whether there were any difference in leg frequency for the dif-  
 ferent background conditions (when synchronized or not), a non-parametric  
 450 repeated-measures ANOVA (Friedman) revealed that background synchroni-  
 zation has no impact on leg frequency ( $\chi^2 = 5.61$ ,  $p = 0.35$ ) nor frequencies’  
 standard deviation ( $\chi^2 = 2.66$ ,  $p = 0.75$ ) (see Figure 8)<sup>2</sup>.

<sup>1</sup>Note that the eye-tracker data of three patients were inoperable due to a bad calibration of the system. Consequently, statistics in this section were therefore performed on 17 subjects.

<sup>2</sup>Note that Vicon data of three patients were lost due to equipment failure. Consequently, the statistics in this section were therefore performed on 17 subjects.

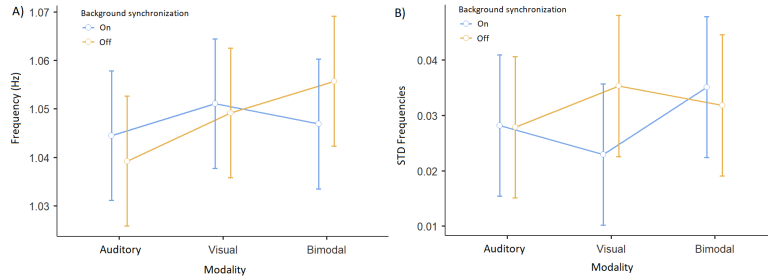


Figure 8: (A) Participant’s frequencies (leg’s motion) against all conditions (B) STD of frequencies against all conditions

We also examined whether there was a correlation between leg’s frequency/standard deviation and reaction times. The correlation of leg’s frequency and reaction times was not significant (Pearson’s coefficient  $r(283) = 0.1, p = 0.09$ ) neither was the correlation of leg’s frequencies’ standard deviation and reaction times (Pearson’s coefficient  $r(283) = 0.004, p = 0.94$ ).

#### 4. Discussion

The goal of the current study was to evaluate the impact of unintentional coordination on visual attention. To do so, we set up an experiment where participants’ attention was challenged by performing three tasks simultaneously while conditions for unintentional coordination to appear were favored. The first task corresponded to an interception task associated with a Stroop test to increase their attentional load and the second task, a reaction time test to alarms in different modalities (auditory, visual and bimodal), were used to assess participants’ attentional load. The third task was a motor task in which participants were asked to swing their legs at a preferred frequency. Two conditions of background synchronization were used. In the synchronization condition, the interface background brightness was synchronizing in real time to participants’ movement by changing in intensity allowing unintentional coordination to appear. In the no-synchronization condition (control condition), the background brightness was not changing at all.

Our results on the reaction time task showed that participants exhibited better reaction times for alarms with the bimodal condition than the auditory condition and lastly with the visual condition. Many studies have demonstrated the benefits of bimodality on reaction times: the redundant signal effect increases when bimodal or trimodal stimuli are presented simultane-

ously leading to a decrease of reaction time compared to unimodal conditions (Hershenson (1962); Fischer & Miller (2008); Schröter et al. (2009)). Moreover, in the case of unimodal stimulus, several studies have shown that an auditory stimulus takes less time than visual stimulus to reach the brain (Kemp (1973); Jain et al. (2015)). Furthermore, in our experiment the visual load was very high making it more difficult to detect a visual alarm than an auditory one. We also looked at the impact of performance in term of targets intercepted on reaction times and no correlation was found meaning that the score wasn't related to reaction times. Lastly, our results also show that participants exhibited a lower reaction time to alarms when the background brightness was synchronizing to them than when it was not moving at all, no matter the alarm modality.

To better understand this latter result, we checked participants' visual strategy using the eye-tracker data. We found that participants made more fixations and spent more time checking on the alarm area when the background brightness was synchronizing to them. Further paired comparisons demonstrated that this result occurred for all alarm modalities but significant only for the visual condition. This makes sense because in the auditory and bimodal conditions, there were no need to check alarm's areas. This result probably means that attentional resources and orientation have been shared across tasks differently for the two conditions with a more efficient management for the synchronizing condition. A study conducted by Chan & DeSouza found that increasing attentional load increases switch costs for pro-saccades (saccades directed towards targets) in term of saccade reaction times and error rate (moving eyes in the right direction) (Chan & DeSouza (2013)). This suggests that, if in the no-movement condition the attentional load was higher, switches between the interception task and the alarm's areas could have been reduced explaining why reaction time was slower than in the synchronization condition for visual alarm modality. However, participants' visual strategy doesn't explain by itself why reaction times were better for other modalities and why there was a change in attentional resource management.

Having the background brightness changing in intensity may have inevitably increased participants perceptual load in term of number of stimuli perceived within their respective perceptual capacity. According to load theory of attentional selection (Lavie (1995); Lavie et al. (2004)), perceptual processing proceeds automatically and involuntarily on all stimuli within capacity. In other words, when perceptual load is high, attentional capac-

ity is exhausted and only relevant stimuli are perceived; alternatively, when perceptual load is low, resources not used can be allocated to non-relevant events. Also according to this theory, attentional capacity is limited and so increasing attention to one task almost always impairs, or at best has no effect on, performance on a second task (Kinchla (1992)). In the case of the experiment of *Temprado et al., 2004*, where participants were performing purposely a bi-manual coordination task while executing a discrete reaction time test, their reaction times were higher in the dual-task condition than in the single-task condition (Temprado & Laurent (2004)). In our experimental design, paying voluntary attention to the background movement was of no specific interest and was not required to succeed. However, motion is a strong salient feature and the movement of the background's brightness was perfectly congruent with the legs' movement of participants so unintentional coordination appeared as an unconscious and unavoidable phenomenon. Hence, one possible explanation for the reaction time reduction might be that unintentional coordination may have helped participants to keep pace and released a part of their attentional resources which have been redirected to the reaction time task. Indeed, at the macroscopic level, our motor actions are coordinated and rhythmic (Hall et al. (2014)) and it is the rhythmic neural activity that shapes the dynamics of motor behavior (Morillon et al. (2019)). We can therefore hypothesize that the background brightness movement had an impact on movement production thanks to the entrainment effect which in turn, could have facilitated rhythm production by bringing an external energy at the right tempo. It could be explained by the fact that intrinsic brain rhythms can be entrained by external rhythms and oscillations of neural excitability have a direct impact on motor and cognitive processes such as selective attention (Calderone et al. (2014)). Some studies have shown that this entrainment to external rhythms was the result of an optimization of neural responses when task-relevant events are expected (Schroeder & Lakatos (2009)). In our experiment, the background oscillation was not in any way congruent with the alarm appearance which was completely random. However, instead of being seen as an irrelevant distractor and ignored, the background movement could have entrained oscillations of neural excitability and helped participants to maintain their pace with no additional cost.

Concerning participants rhythm, we have checked for each condition if there were any difference in participants' motor control which could reflect disturbance in term of frequency/stability. To do so, we have checked their

legs' movement frequency. No difference across all conditions were found,  
555 the synchronization of the background brightness didn't disturb participants'  
motor control but did not increased their stability either. **Moreover, no corre-  
lation between reaction times and legs' frequency/stability were found mean-  
ing that neither frequency nor its stability was related to reaction times.** In  
the current study, the background oscillations occurred at subject's preferred  
560 frequency, adapting in real time. We made this choice because we wanted  
to maximize the chance for unintentional coordination to appear while ob-  
serving the greatest stability. Indeed, when the difference between preferred  
leg frequency and stimulus frequency becomes too high, coordination cannot  
be reached. However, it would be interesting to see in future work extent  
565 to which the stimulus synchronizing in real time had an impact on reaction  
time by testing different frequencies away from the preferred frequency of  
participants.

In conclusion, our study suggests a beneficial effect of unintentional envi-  
ronmental coordination on attentional resource allocation at least for a visual  
570 stimulus and when the environmental rhythm is at participants' preferred fre-  
quency. It supports the idea that, when possible, human-machine interface  
would benefit from a rhythmic adaptability to their interaction partner to  
make interaction not only more pleasant but also more efficient.

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## 6. Conflict of interest/Competing interests

Declarations of interest: none.

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